SMALL GRAINS FORAGE MANAGEMENT AND EVALUATION IN CENTRAL TEXAS

A Thesis

by

AARON MICHAEL FRANKS

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Approved by:

Chair of Committee,	Amir M. H. Ibrahim
Committee Members,	Robert W. Duncan
	Larry A. Redmon
	Tony L. Provin
	Jason E. Sawyer
Head of Department,	David D. Baltensperger

May 2013

Major Subject: Agronomy

ABSTRACT

Hard Red Winter (HRW) and Soft Red Winter (HRW) wheat classes (*Triticum aestivum* L.) and oat (*Avena sativa* L.) are commonly established as a source of winter and spring forage for cattle grazing in many regions of Texas and the U.S. Southern Great Plains. Small grains used in these grazed systems offer the flexibility of management for season long forage production or production of both forage and grain (dual-purpose). Many commercially available and experimental cultivars are continually evaluated on their ability to produce grain, but little yield data is available on wheat and oats under dual-purpose management systems. In forage production systems, soil fertility management is also an integral component in meeting specific yield goals that producers depend upon to sustain adequate animal performance. Current nitrogen (N) recommendations in Texas are based on heavy, moderate, and light levels of grazing. To address these issues, two-year studies were initiated at three locations in Central Texas. The objectives of these studies were; (1) to evaluate thirty wheat and ten oat cultivars based on forage production and grain yield to identify those best suited to dual-purpose management; (2) to determine winter wheat forage yield potential at varying levels of N fertility; and (3) to evaluate five minimally invasive and non-destructive methods of quantifying forage yield.

Results from dual-purpose cultivar evaluations included significant differences in forage yield, nutritive value, and grain yield between cultivars and species. Overall, oat produced less forage than either class of wheat, but Mg content was generally higher in

oat. For grain production, SRW performed better under irrigation, but in dryland situations both wheat classes performed equally. We also found that pre-plant N fertilizer significantly reduced stand establishment in dry environments. The 67 kg ha^{-1} pre-plant N and the 45 kg ha^{-1} top-dress rates produced the highest forage yield. Nutritive value generally increased as N application rate increased, even when no yield increase was observed. Hand clipping and canopy height both correlated very well with full plot harvest and visual ratings and NDVI had moderate relationships with full plot harvest. The relationship between ground cover and dry matter yield was variable and only weakly correlated.

DEDICATION

I dedicate this thesis to my parents, M.D. and Barbara Franks, and my grandparents, Don and Helen Franks, and Raymond and Mary Schlabs. Without their guidance, support, and more than occasional tail whipping, I would not be the driven individual I am today. They instilled in me a work ethic and love of the land and agriculture, leading me to pursue this degree. I am very grateful that the Lord saw it fit for me to have them.

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Amir Ibrahim, and my committee members, Dr. Robert Duncan, Dr. Lary Redmon, Dr. Jason Sawyer, and Dr. Tony Provin for their help and guidance throughout the course of this research and my master's program.

A special thanks goes to Daniel Hathcoat who devoted countless hours in the field and on the road to ensure that field research went smoothly and was completed in a timely manner. Thanks also go to Kyle Schwertner, Jordan Maldonado, Austin Richards, Alfredo DelGado, Francis Beecher, Sean Thompson for their aid with the arduous field work that accompanied these studies

I would also like to thank all of my classmates, and the teaching and business staff of the Soil and Crop Sciences Department, who became my Texas A&M family, for all their help, support, and guidance along the way.

Finally, I would like to give a big thanks to my mother. Without her love, support and constant pestering, I would not have completed this thesis and degree.

NOMENCLATURE

HRW	Hard Red Winter Wheat
SRW	Soft Red Winter Wheat
HRS	Hard Red Spring Wheat
HW	White Wheat
NDVI	Normalized Difference Vegetative Index
ASTREC	Animal Science, Teaching, Research, and Extension Complex
NIR	Near Infrared Spectrophotometer
CP	Crude Protein
ADF	Acid Detergent Fiber
NDF	Neutral Detergent Fiber
ADL	Acid Detergent Lignin
IVDMD	In Vitro Dry Matter Digestibility
TDN	Total Digestible Nutrients
UAN	Urea Ammonium Nitrate
MRT	Multiple Range Test

TABLE OF CONTENTS

CHAPTER Page

LIST OF FIGURES

LIST OF TABLES

CHAPTER I

INTRODUCTION

Wheat (*Triticum aestivum* L.) is a staple in the diets of many people around the world, providing more nourishment for people than any other food source (Briggle and Curtis, 1987). On average world wheat production totals 653 million metric tons per year. The top wheat producing countries in 2011 included China, India, Russia, and the United States. Of these the largest producer of wheat was China, which grew a total of 117 million metric tons. The United States ranked fourth in world wheat production, producing 54 million metric tons (FAO, 2012).

In the United States, wheat production is fairly wide spread, ranking third in both planted area and gross receipts, behind corn and soybeans (ERS, 2012c). The USDA identifies three major wheat production areas that together grow 75% of the nation's wheat annually. These regions include the Northern and Southern Great Plains, the North Central region, and the Pacific region. Of these regions, Texas, Kansas, and Oklahoma are responsible for around 40% of annual wheat product, with 8.66 million ha planted annually (NASS, 2012a).

In Texas, winter wheat is planted on an average of 2.5 million ha annually (NASS, 2012a). In 2011, of the 2.28 million ha planted in Texas, only 0.81 million ha were harvested due to inadequate rainfall or use of the crop for purposes other than grain production. On average, 1.18 million ha are harvested for grain in Texas annually with a value of production near $440 million per year (NASS, 2012a).

The USDA also identifies 5 classes of wheat grown in the United States, with the divisions based on characteristics such as hardness, seed color, and growing season. The most common of these is HRW wheat followed by SRW wheat, hard red spring wheat (HRS), white wheat (HW), and durum wheat. Each class of wheat produces flour with unique characteristics that make them suitable for different baked goods (Briggle and Curtis, 1987; ERS, 2012b).

Oat (*Avena sativa* L.) is less commonly grown around the world, but is consumed in many countries. Over the ten-year period from 2002 to 2011, world average annual oat production totaled 25 million metric tons. In 2011, Russia led world oat production, producing 5.3 million metric tons. The United States ranked fifth in world oat production that year, with production totaling 779,000 metric tons (FAO, 2012). The United States produces an average of 1.4 million metric tons annually (NASS, 2012a).

In the United States, oat production is much less wide spread as compared to wheat production, with major production areas located in the Northeast, North Central, Northern Plains, Pacific, and Southern Plains regions (ERS, 1997). Texas leads the nation in oat acreage, averaging 264,000 hectares seeded annually. Only one sixth of this area is harvested for grain each year, but generates an average of $13.2 million each year (NASS, 2012a). Widespread use of oat as a forage crop probably has a significant impact on the number of hectares harvested. Grain oat is predominately used as animal feed, but is also used in foodstuffs and body care products, and as a raw material for furfural production.

Winter wheat and oat are versatile crops that can be used in several management systems. Winter wheat may be grown for grain production, forage only (graze-out), or for both forage and grain (dual-purpose) (Holliday, 1956; Holt, 1962; Redmon, et al., 1995b). Across the United States, management of winter wheat for grain production is most prevalent, but many producers in the Southern Great Plains region also manage these crops to allow for the utilization of forage produced in the fall, winter, and spring. It is estimated that 30-80% of the total wheat acres planted in the southern Great Plains are grazed by cattle (*Bos ssp.*) at some point during the growing season and 10-20% are grazed exclusively (Carver, et al., 1991; Pinchak, et al., 1996). Texas, Oklahoma, and Kansas are the major producers in this area, with an annual mean of 8.66 million hectares planted (NASS, 2012a) and 2.6 million head pastured on these small grains swards annually (NASS, 2012b).

In graze-out and dual-purpose systems, as in others, management decisions like cultivar selection and soil fertility are essential to ensuring profitability. With little regional fertility and cultivar performance data available (Nelson, 1983; Pinchak, et al., 1996), producers utilizing dual-purpose and graze-out small grains systems are forced to rely on past experience and grain production data in attempt to maximize the profitability of these systems. Recent increases in the cost of labor, fuel, fertilizer, and other inputs increases the need for research to identify management practices that maximize resource use efficiency. To provide information specific to forage and forage and grain production, two year research trials were initiated in central Texas to address the following research objectives: 1) identify wheat and oat cultivars that maximize forage and grain yield under dual-purpose management, 2) ascertain the response of winter wheat forage production and nutritive value to varying rates of N application, and 3) evaluate destructive, minimally invasive, and non-destructive forage quantification methods to determine whether non-destructive and minimally invasive methods are viable substitutes for destructive methods. A review of literature, materials and methods, and data from these studies is discussed in subsequent chapters.

CHAPTER II

LITERATURE REVIEW

Overview

Winter wheat and oat have a special niche in the Southern Great Plains region. Although wheat and oat are most commonly grown for grain in other parts of the country, Southern producers often utilize the highly nutritive forage produced in the fall, winter, and spring as a source of fodder for grazing animals when other forage resources are generally low in supply, nutritive value, and digestibility (Lyon, et al., 2001; Beck, et al., 2005). In this region, these cool-season annual forages are the primary source of herbage used to pasture growing beef cattle (Redmon, et al., 1995b) and provide farmers and ranchers with management options to increase the profitability of their enterprises.

Grazed winter wheat systems also offer a unique opportunity to manage farm risk in relation to commodity prices and production goals. The multiple production avenues offered by these systems allow producers to exploit changes in market value by shifting production emphasis to the more valuable commodity. In a situation where markets or producer goals justify retained ownership, dual-purpose systems can accommodate these actions, with the ability to revert to a graze-out system late in the season. Producing multiple commodities in one enterprise also achieves a level of diversification that reduces the economic risk of producing either commodity alone (Krenzer, et al., 1992). In an economic study conducted by Epplin et al. (2001), the authors found that dual-purpose net returns exceeded that of grain-only production in 16 of the 20 years analyzed. Redmon et al. (1995a) found that on average, grazing and grain production enterprises derived 59% of total net returns from grain production and 41% from cattle gains, proving that both commodities produce significant returns. With recent economic instability and very volatile commodity markets, the management options associated with grazed small grains systems can be a valuable asset.

Winter wheat and oat used in grazing applications fit into one of two management systems, dual-purpose and graze-out. In dual-purpose systems, producers graze winter wheat during stages of vegetative growth, and then remove grazing animals in the spring shortly after floral initiation but prior to rapid culm elongation. This allows the crop to continue into reproductive growth without injury and produce grain (Donnelly and McMurphy, 1983; Epplin, et al., 2000). Grain yield is reduced markedly in stands grazed after meristematic tissue reaches a height prone to removal by livestock (Donnelly and McMurphy, 1983; Epplin, et al., 2000). When intended for use as forage only, the crop is grazed until regrowth ceases. In these situations, forage production is much greater, since winter wheat dry matter accumulation is greatest during stem elongation and floral initiation (Daigger, et al., 1976). In some cases, total forage yield for graze-out pasture can be three times that of swards where grazing is terminated at first hollow stem (Donnelly and McMurphy, 1983).

Nutritive Value

In grazed systems, the primary goal is to produce forage of sufficient quality and quantity to meet or exceed the nutrient requirements of the animal. Forage quality is determined by the physical and chemical composition of fodder, as well as the palatability as perceived by the animal and overall animal performance. Concentrations of N, P, K, Mg, and Ca are considered to be major factors influencing animal health and performance. Wheat and oat produce a valuable, high-quality forage capable of sustaining the nutrient requirements of all grazing animals, regardless of class or species (Horn, 1983). Crude protein content of wheat in its vegetative state is often in excess of 25% (Croy, 1983b).

Forages are generally evaluated based on the broad categories of crude protein content (N% x 6.25) and digestible energy. Small grain pasture generally offers these nutrients in excess of the requirements for growing steers gaining 0.9 kg day^{-1} established in National Research Council (1996), but other constituents of forage nutritive value and digestibility are also of concern in grazed systems. Although plant maturity is one of the most influential factors in dictating forage nutritive value and digestibility (Cherney and Marten, 1982), forage species and soil fertility also have an affect. The literature suggests that differences in nutritive value and digestibility exist between cool-season small grain species. In a study conducted by Cherney and Marten (1982), the authors found that barley was superior to other small grains in terms of digestibility factors, and macromineral concentrations. Differences between cultivars within species have also been noted, but any advantage of one cultivar over another is generally small and inconsistent across locations and years (Rommann, et al., 1982; Croy, 1983b; Donnelly and McMurphy, 1983). It has also been reported that soil nutrient status influences nutrient concentrations in forages (Daigger, et al., 1976; Horn, 1983).

Stewart, et al. (1981) reported elevated forage N and K concentrations when N fertilizer was added. Although N in forages is of value, elevated N and K concentrations relative to Ca and Mg concentrations have been implicated in causing nutrition disorders in cattle. Milk fever (hypocalcemia) and grass tetany (hypomagnesemia) are common ailments of lactating cattle, but can also afflict young stocker steers that generally graze small grains, with tetany being most prevalent (Horn, et al., 2005). It has been suggested that when forage Mg content falls below 0.2%, or when the ratio of K to the sum of Ca and Mg exceeds 2.2, tetany may become a problem (Stewart, et al., 1981; Grunes, et al., 1983).

Management Considerations

Different considerations must be taken into account with each management system. In central Texas, dual-purpose and graze-out wheat is generally planted one month to 45 days prior to stands planted for solely for grain production (Epplin, et al., 2000; Carver, et al., 2001; Hossain, et al., 2003). A higher seeding rate, 100 kg ha^{-1}, is also generally used in these situations (Redmon, 2011). Early planting and seeding at higher density allows for greater forage production prior to winter dormancy and an extended grazing period, ultimately enabling greater weight gains and increased profitability. However, early planting can also adversely affect the crop due to increased exposure to biotic and abiotic stresses (Carver, et al., 2001; Khalil, et al., 2002). With their host present earlier in the season, aphids (*Schizaphis graminum* Rondani, *Rhopalosiphum padi* L.) are able to enter a field and multiply earlier, bringing with them a heightened risk of *Barley yellow dwarf virus* and desiccation (Carver, et al., 2001). In regions where yearly precipitation is low, early planting, high seeding rate, and forage removal may exhaust soil moisture earlier in the season than would otherwise be removed, leading to increased probability of drought stress and reduced grain yield.

It is important to understand that historically, winter wheat breeding programs in the Southern plains select breeding lines and evaluate their performance based on grain yield and quality from stands planted in mid-October (Winter and Thompson, 1990; Krenzer, et al., 1992; Carver, et al., 2001). These methods allow them to make selections under conditions similar to those that would occur in producer fields meant for grain only production. With little or no direct selection pressure placed on above ground biomass yield, the resulting lines have a genetic shift to greater grain production, and may not be as suitable for management systems that include forage utilization (Winter and Thompson, 1987; Carver, et al., 2001). In the past, grazing was seen as an acceptable and sometimes necessary method to reduce lodging prior to the introduction of semi-dwarf cultivars, that may actually suffer from reduced leaf area (Winter, et al., 1990). Furthermore, breeding lines that may be particularly well suited for forage production can be lost in selection processes where this attribute is not evaluated, as grain and forage yield correlations have been found to be insignificant or negative (Atkins, et al., 1969; Ud-Din, et al., 1993; Krenzer, et al., 1996). Plausible explanations for the lack of emphasis placed on forage evaluation include limited resources and the added labor involved in evaluating lines in a more complicated management scheme (Atkins, et al., 1969; MacKown and Carver, 2005). Limited seed supply coupled with the need to increase seed for continued selection and evaluation also poses a problem to breeders, which points to a need for alternative biomass evaluation methods that allow for less destructive or completely non-invasive quantification of forage production. With methods that better fit constrains of breeding programs, forage line development may become a more plausible venture.

Cultivar selection is generally deemed to be a management decision crucial to the successful implementation and profitability of any cropping system (Krenzer, et al., 1992). Traits of primary concern when selecting small grain cultivars for use in pasture settings include forage yield potential, nutritive value potential, and forage production interval. Initiation date of stem extension and grain yield traits are also of interest for dual-purpose systems (Worrall and Gilmore, 1985; MacKown and Carver, 2005). Croy (1983a) found that jointing time varied as much as a month between wheat cultivars. Sufficient grain yield data is available through breeding and extension programs, but little research has been conducted to delineate cultivars in relation to traits of interest mentioned above, with little or no data for the Central Texas region. It has been noted in literature that substantial differences in forage production were evident between cultivars of winter wheat (Worrall and Gilmore, 1985; Krenzer, et al., 1992). Differences in nutritive value between species and cultivars within species have also been noted (Helsel and Thomas, 1987).

Fertility

Fertility management also plays a major role in the performance of forage and grain production systems, as well as the performance of grazing animals. Soil levels of available N, P, and K, along with vital micronutrients can limit yield and nutritive value of the forage and grain produced. Of these, N is known to be the most commonly limiting nutrient in soils due to abundant plant use and the many mechanisms by which N is lost from the root zone (Donnelly and McMurphy, 1983). The cost of N fertilizer has also increased drastically in recent years, almost tripling in price from 2002 to 2012 (ERS, 2012a). Currently, the Texas A&M University Soil, Water, and Forage Testing Laboratory makes N rate recommendations for grazed winter wheat swards based upon the nominal categories of heavy, moderate, and light grazing intensity (Texas A&M AgriLife Extension Service, 2012b). To improve this managerial tool, N rate recommendations might be made based on a specific yield goal, which can then be converted into animal unit days. Many producers use this measure to determine stocking density. These facts suggest a need for additional research in the areas of cultivar performance and N fertility management in grazed winter wheat systems to allow for enhanced efficiency of these systems in the Central Texas region by providing producers the information they need to make the most profitable management choices.

Forage Sampling Methodologies

There also exists some question as to the best method of quantifying biomass yield for forage research. Several methods have been utilized in previous research including the use of hand tools to clip a sub sample from plots (Hubbard and Harper, 1949; Holt, 1962; Hansen and Schjoerring, 2003; MacKown and Carver, 2005) and the mechanized harvest of the entire plot (Worrall and Gilmore, 1985; Helsel and Thomas, 1987; Hossain, et al., 2003). Some non-destructive yield estimation methods have also been employed including estimations based on plant height (Freeman, et al., 2007), visual ratings(Atkins, et al., 1969; Ud-Din, et al., 1993), and Normalized Difference Vegetation Index (NDVI) readings (Hansen and Schjoerring, 2003; Moges, et al., 2005; Freeman, et al., 2007). Little consensus exists as to the best method of sampling for quantification purposes, as spatial variability is a major limiting factor in forage yield determination. Continued research in the field of forage production is essential to increase the efficiency with which these systems operate so they may help to provide for an ever-increasing world population.

CHAPTER III

EVALUATION OF WINTER WHEAT AND OATS UNDER DUAL-PURPOSE MANAGEMENT IN CENTRAL TEXAS

Introduction

Winter wheat and oat have a special niche in the Southern Great Plains region. Although wheat and oat are most commonly grown for grain in other parts of the country, Southern producers often utilize the highly nutritive forage produced in the fall, winter, and spring as a source of fodder for grazing animals when other forage resources are generally low in supply, nutritive value, and digestibility (Lyon, et al., 2001; Beck, et al., 2005). In this region, these cool-season annual forages are the primary source of herbage used to pasture growing beef cattle (Redmon, et al., 1995b) and provide farmers and ranchers with management options to increase the profitability of their enterprises. It is estimated that 30 - 80% of the total wheat acres planted in the southern Great Plains are grazed by cattle (*Bos ssp.*) at some point during the growing season (Carver, et al., 1991; Pinchak, et al., 1996). Texas, Oklahoma, and Kansas are the major producers in this area, with an annual mean of 8.66 million hectares planted (NASS, 2012a) and 2.6 million head pastured on these small grains swards annually (NASS, 2012b).

Wheat and oat produce a valuable, high-quality forage capable of sustaining the nutrient requirements of all grazing animals, regardless of class or species (Horn, 1983). It is common practice for producers to graze winter wheat during stages of vegetative growth, and then remove grazing animals in the spring shortly after floral initiation but prior to rapid culm elongation. This allows the crop to continue into reproductive growth stages and produce grain (Donnelly and McMurphy, 1983; Epplin, et al., 2000). Grain yield is reduced markedly in stands grazed after meristematic tissue reaches a height prone to removal by livestock (Donnelly and McMurphy, 1983; Epplin, et al., 2000).

Cultivar selection is generally deemed to be a management decision crucial to the successful implementation and profitability of any cropping system (Krenzer, et al., 1992). Traits of primary concern when selecting small grain cultivars for use in pasture settings include forage yield potential, nutritive value potential, forage production interval, initiation date of stem extension, and grain yield (MacKown and Carver, 2005). Croy (1983a) found that jointing date varied as much as a month between wheat cultivars. Several authors have cited that little difference in nutritive value between cultivars within small grains species has been observed (Horn, et al., 1981; Donnelly and McMurphy, 1983), but many of the cultivars tested are no longer in production. Sufficient grain yield data is available through breeding and extension programs (Texas A&M Agrilife Extension Service, 2012c), but little research has been conducted to delineate cultivars in relation to traits of interest mentioned above, with little or no data for the Central Texas region. It has been noted in literature that substantial differences in forage production were evident between cultivars of winter wheat (Worrall and Gilmore, 1985; Krenzer, et al., 1992). In an 11-year study conducted by Worrall and Gilmore (1985) two hard red winter wheat cultivars, Lancota and Improved Triumph, yielded more above ground biomass than TAM W-101. Differences in nutritive value between species and cultivars within species has also been noted (Helsel and Thomas, 1987).

It is important to understand that historically, winter wheat breeding programs in the Southern plains select lines and evaluate their performance based on grain yield and quality from planting in mid-October to November (Winter and Thompson, 1990; Carver, et al., 2001). These methods allow them to make selections under conditions similar to those that would occur in producer fields meant for grain only production. With little or no direct selection pressure placed on above ground biomass yield, the resulting lines may not be as suitable for management systems that include forage utilization (Winter and Thompson, 1987; Carver, et al., 2001). In the past, grazing was seen as an acceptable and sometimes necessary method to reduce lodging prior to the introduction of semi-dwarf cultivars (Winter, et al., 1990). Furthermore, breeding lines that may be particularly well-suited for forage production can be lost in selection processes where this attribute is not evaluated, as grain and forage yield correlations have been found to be insignificant or negative (Atkins, et al., 1969; Ud-Din, et al., 1993). Plausible explanations for the lack of emphasis placed on forage evaluation include limited resources and the added labor involved in evaluating lines in a more complicated management scheme (Atkins, et al., 1969; MacKown and Carver, 2005). Limited seed supply coupled with the need to increase seed for continued selection and evaluation also poses a problem to breeders, which points to a need for alternative biomass evaluation methods that allow for less destructive or completely non-invasive quantification of forage production.

To address the lack of information on cultivar performance under dual-purpose management, a two year field study was initiated in three location in central Texas to identify HRW, SRW, and oat cultivars that possess superior forage and grain yield traits in dual-purpose management systems. The results from these trials will yield management type specific information that can be used by producers when selecting species and cultivars to utilize in dual-purpose management systems.

Materials and Methods

Experimental Locations

This research was initiated at three locations in central Texas. The first was located in the Brazos River Flood Plain (Brazos Bottom) near Snook, TX at the Texas A&M AgriLife Extension Farm (30° 30’ N lat; 96° 25’ W long; 66 m elevation above sea level.) This location is a Belk clay soil (fine, mixed, thermic Entic Hapluderts) exhibiting 0 to 1 % slopes. These soils are well drained with very slow permeability and high water holding capacity. The soil capability classification is 3S for non-irrigated, but was irrigated both years of the study. The second experimental location near College Station, TX at ASTREC (30° 33’ N lat; 96° 24’ W long; 83 m elevation above sea level.) The soil type is a Roboco loamy fine sand (loamy, siliceous, active, thermic Aquic Arenic Paleustalfs) with a 1 to 3 % slope, moderate drainage, and rapid permeability in the upper layer with slow permeability in the subsoil. Large or repeated rainfall events can lead to a perched water table 0.5 to 1 m from the soil surface. The soil capability classification is 2E for non-irrigated. The third location was near McGregor, TX at the Texas A&M Agriculture Research and Extension Center (31° 22´ N lat; 97° 27´ W long;

240 m elevation above sea level). Soil type is a Slidell clay (fine, montmorillonitic, thermic Udic Haplusterts) with a 0- to 2 % slope, very slow permeability, and a high water holding capacity. The soil capability subclass was 2E for dryland and none was irrigated (NRCS, 2012).

This trial evaluated the performance of 38 commercially available cultivars, including 24 HRW cultivars, 6 SRW cultivars, and 8 oat cultivars under dual-purpose management. Dual-purpose management entails the utilization of forage prior to culm elongation, then production of grain, thus both forage and grain yield were measured. The trial was laid out in a completely randomized block design with each cultivar replicated four times. Plots 1.5 m wide and 4.5 m long were used in this experiment.

Production Practices

In mid-to late-August, plot areas were disked or plowed to prepare the seedbed. Prior to planting, 15 cm composite soil samples were obtained from each study location and submitted to the Texas A&M Soil, Water, and Forage Testing Lab for analysis. Soils at each location were amended with granular urea (46-0-0) and triple super phosphate (0-46-0) to meet specified soil test recommendations. Fertilizers were applied with a calibrated pendulum-type spreader and then incorporated with harrows or with the wheat drill if applied directly before planting.

All seed was treated with the label rate of Gaucho XT® to prevent seedling disease and early-season insect damage. All cultivars were seeded at the rate of 100 kg ha^{-1}, the recommended rate for seeding small grains for forage production in central

Texas (Redmon, 2011). Test plots were seeded in mid-to late-September, using a seven row Hege 500 small plot drill (Hege Equipment Inc., Colwich, KS) with 16.5 cm row spacing. The planter was equipped with a cone type seed-metering device calibrated to plant a plot 1.5 m in width and 6 m in length. After emergence of seedlings in the experimental units, 1.5 m alleyways between replications were seeded, yielding 1.5 m wide, 4.5 m long plots for evaluation. This was done to ensure uniform stands over the experimental unit and to reduce any edge affect that would have resulted from blank alleys. Seedling establishment data was also collected shortly after emergence. Stand counts were taken from three 30 cm lengths of interior row and then averaged to serve as a representative plot sample.

Plots were maintained to be free of weed and insect pressure. Applications of 2,4-D (0.5 L ha^{-1}) and Dimethoate (0.25 L ha^{-1}) were used to control any early season weed and insect infestations. Irrigation was available at the Brazos Bottom location and was used to combat water stress due to severe drought conditions. Irrigation was applied on an as needed basis and differed between years. In 2011, water was only applied when drought stress was apparent, in 13 mm increments. In 2012, water was applied generously at a rate of around 38 mm every two weeks in periods where rainfall did not meet this threshold.

Forage Yield and Nutritive Value

Forage yield and nutritive value were determined by one to two cuttings prior to the upward movement of merristematic tissue at each location. Plots were harvested with a Loftness flail type forage harvester equipped with a R-Tech Alfalfa-Omega weigh platform (R-Tech Industries Ltd, MB, Canada). Clipping height averaged 1.5 - 2.5 cm. Total plot weights were taken immediately following harvest and subsamples were taken and weighed in the field using a digital balance capable of measuring a tenth of a gram. These subsamples were then dried in a forced air oven at 65° C for a minimum of 48 hours to ensure they were devoid of moisture. Once removed from the oven, they were allowed to return to room temperature and weighed again to obtain a dry sample weight. The wet and dry sample weights were then used to determine the total dry matter biomass for each plot.

After the drying and weighing processes were complete, samples were ground to pass through a 1 mm screen, in preparation for nutritive value testing. Nutritive values were determined using a Unity Scientific SpectraStar™ 2500 near infrared spectrophotometer (NIR) (Foss, Hillerod, Denmark). To initiate the calibration procedure chemical methods were used to determine the chemical and physical composition of a sub set of 65 diverse samples from the studies discussed in this thesis. Constituents measured include crude protein (CP) determined through high temperature combustion, acid detergent fiber (ADF), neutral detergent fiber (NDF), and acid detergent lignin (ADL) determined gravimetrically after liquid digestion, in vitro dry matter digestibility (IVDMD) determined after digestion in harvested rumen fluid, and P, K, Ca, and Mg determined through ICP analysis of nitric acid digest (Texas A&M AgriLife Extension Service, 2012a). These values were then used to parallel NIR derived values, generating a starting calibration equation. After this point, any samples that generated statistical outliers were chemically tested and added to the calibration equation. Additional information on the use of NIR calibration for the prediction of forage nutritive value can be found in Roberts, et al. (2003).

After forage harvest was complete, plots were allowed to regrow with the intent of producing grain. At jointing (Feeks 6), plots were top dressed with 56 kg ha^{-1} N in the form of urea ammonium nitrate (UAN). At this time pest control products were also administered on an as-needed basis. Finesse® Grass and Broadleaf herbicide (52 g ha^{-1}, chlorosulfuron and flucarbozone sodium) was used to control any weed infestations present. To reduce yield losses due to insect pressure, applications of Dimethoate (0.25 L ha^{-1}) were made. Insect infestations including Greenbug (*Schizaphis graminum*), bird cherry-oat aphid (*Rhopalosiphum padi*), and army worm (*Pseudaletia unipuncta*) were observed and controlled. To control severe fungal infestations such as leaf rust (*Puccinia graminis*), applications of Quilt® Fungicide (1 L ha^{-1}, azoxystrobin and propiconazol) were made.

Immediately prior to harvesting grain, plots were rated for lodging. Severity of lodging was rated on a scale from 1 to 10, where a rating of 1 represented little lodging and a rating of 10 represented severe lodging. Grain was harvested using a Massey Ferguson 8XP small plot combine (Massey Ferguson, Duluth, Georgia) and placed in 4.54 kg paper bags. Prior to cleaning, oat samples were deawned and foreign matter in all samples was removed using a Hege grain sieve and aspirator (Hege Equipment Inc., Colwich, KS). After the cleaning process was complete, total weight was determined for calculation of plot yield. To determine bushel weight and moisture content, seed was processed using a Dickey John GAC 2100 Grain analyzer (Seedburo, Des Plaines, IL). An analysis of protein content was also conducted using an Infratec 1226 NIR spectrometer grain analyzer (Foss, Hillerod, Denmark). Plot yield in kg ha^{-1} was calculated from total weight and corrected for harvested plot length, then standardized to 12.5% moisture content.

Statistical Analysis

Statistical analysis was conducted with SAS version 9.3 (SAS Institute Inc., Cary NC) (SAS Institute Inc., 2011) using the general linear model to perform analysis of variance and Duncan's MRT to determine mean separations. Homoscedasticity was tested using Bartlett's test for homogeneity of error variances and correlation was determined through the use of Pearson's product-moment correlation.

Results and Discussion

Seedling Establishment

Stand data was taken shortly after seedling emergence. The primary concern with stand establishment was to determine the degree to which it affected subsequent forage and grain yield.

Analysis of variance showed significant differences in stand establishment were present between cultivars (P<0.01) and environments (P<0.01). There was also a significant interaction between these main effects (P<0.01). Factors such as seed viability and coleoptile length may be responsible for the differences observed between cultivars. Differences between environments may be explained by differing soil moisture at planting, timing and extent of precipitation events, and soil tilth. To determine if there was any effect of stand establishment on later forage and grain yield, Person's correlation coefficients were calculated. Strong positive correlations were found between stand establishment and each of initial forage yield (r = 0.655 P<0.01), total forage yield (r = 0.53 P<0.01), and grain yield (r = 0.316 P<0.01). Of these, the relationship between stand establishment and grain yield is most astonishing, as small grains and wheat in particular have the ability to tiller and take advantage of available moisture and nutrients. Stress generated through loss of nutrients and moisture due to biomass removal may have limited the potential number of tillers and yield potential.

Forage Yield

Forage yield was determined through one to two forage clippings at each location each year. In both the 2010-2011 and the 2011-2012 seasons, only the irrigated Brazos Bottom location produced enough forage to justify multiple harvests. Other locations lacked adequate above ground biomass accumulation due to severe drought conditions experienced throughout the 2010-2011 season and early in the 2011-2012 growing season. Planting and harvest dates for all locations are presented in Table 1. Recorded and average monthly precipitation totals for the College Station and McGregor areas, adapted from National Weather Service data (2012a), can be found in Fig. 1 and Fig. 2, respectively.

Table 1. Planting and harvest dates at ASTREC, the Brazos Bottom, and McGregor, TX in the 2010-2011 and 2011-2012 growing seasons.

Year	Location†	Planting Date	Forage Harvest Date(s)	Grain Harvest Date‡
2011				
	ASTREC	9/21/10	1/28/11	5/4/11
	Brazos Bottom	9/21/10	12/9/10	5/11/11
			2/3/11	
	McGregor	9/30/10	3/4/11	5/19/11
2012				
	Brazos Bottom	9/22/11	12/1/11	5/3/12
			1/20/12	5/9/12
	McGregor	9/30/11	1/6/12	5/18/12

† ASTREC, Animal Science, Teaching, Research, and Extension Complex.

‡ Two grain harvest dates indicated for BB 2012, the first for wheat, the second for oat.

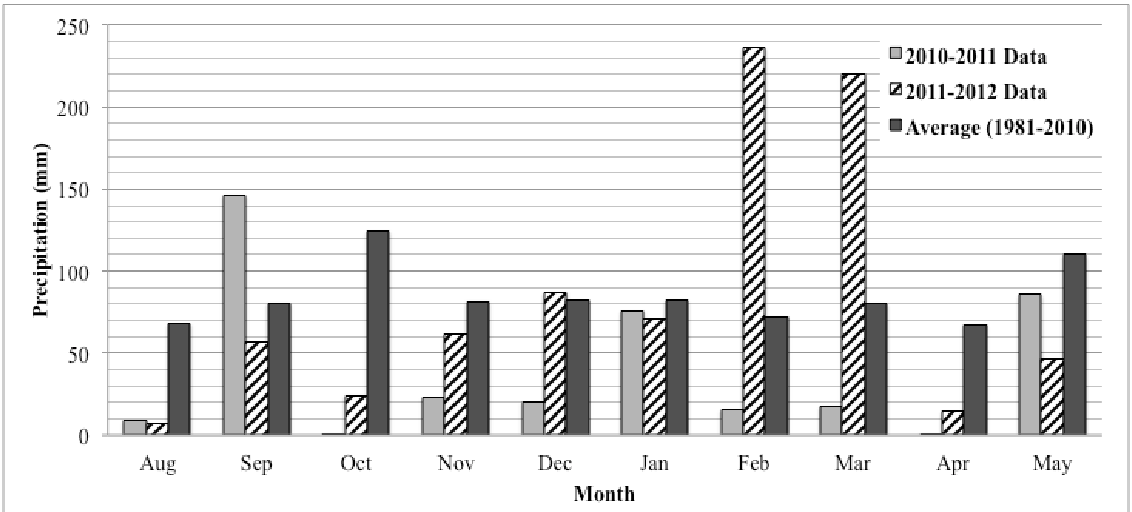

Fig. 1 Monthly average and recorded precipitation for College Station, Texas in the 2011 and 2012 growing seasons (National Weather Service, 2012a).

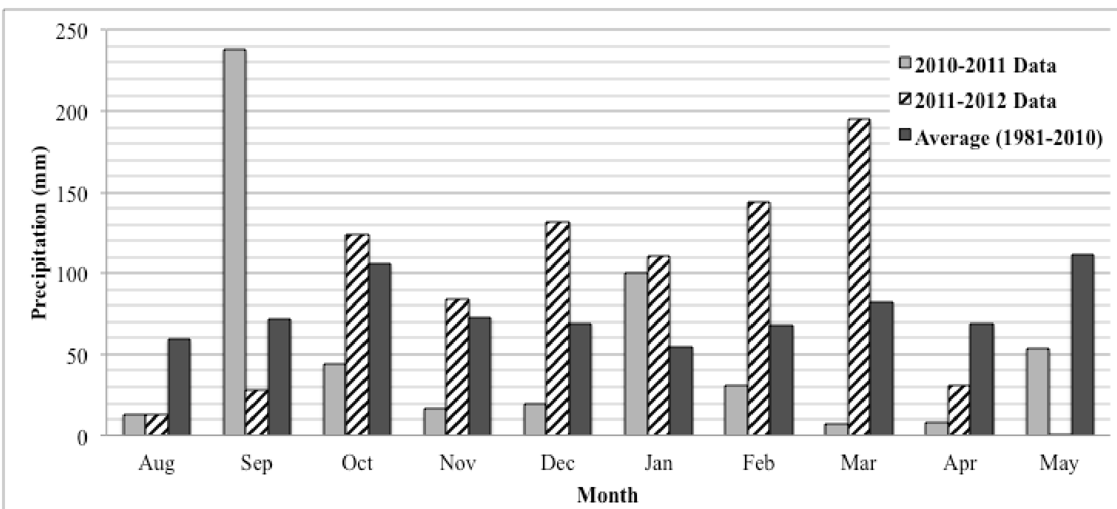

Fig. 2 Monthly average and recorded precipitation for McGregor, Texas in the 2011 and 2012 growing seasons (National Weather Service, 2012b).

Early season forage yield (harvested prior to December 15) at the Brazos Bottom ranged from 743 to 2944 kg ha^{-1} in 2011 and from 2960 to 5761 kg ha^{-1} in 2012 (Tables 2 and 3). When analyzed across years, no significant differences between cultivars (P=0.23) existed, but highly significant year (P<0.01) and year by cultivar (P<0.01) interactions were observed. These interactions are most likely due to the differences in precipitation and irrigation regime between years.

Late season forage yield at the Brazos Bottom ranged from 1241 to 2415 kg ha^{-1} in 2011 and from 1323 to 3490 kg ha^{-1} in 2012 (Tables 4 and 5). When analyzed across years, differences in late season forage production between cultivars were highly significant (P<0.01). As in the early season forage production, there were highly significant year (P<0.01) and year by cultivar (P<0.01) interactions.

When comparisons were made between endosperm type and species for early and late season dry matter yield, significant differences were observed (Table 6). Means separation tests conducted using Duncan's multiple range test and significant p values indicate that the two wheat classes included in this study outperformed oat in both early and late season forage production. In an Oklahoma wheat forage study conducted by Carver, et al. (1991), the authors found that SRW produced more winter forage and HRW produced more spring forage. Our findings for 2011 follow that trend but no appreciable differences between wheat classes were seen either year (Table 6). Data was not combined across years due to a significant interaction between year and dry matter yield.

Table 2. Mean early season forage yield at the Brazos Bottom, College Station, TX in 2011.

Cultivar	Type †	Duncan Grouping ‡	Forage Yield kg ha^{-1}
Doans	HRW	A	2,945
Heavy Grazer 76-30	Oat	A B	2,738
Fannin	HRW	A B C	2,685
TAM 112	HRW	A B C D	2,515
LA 841	SRW	A B C D E	2,367
TAM 304	HRW	A B C D E	2,343
Billings	HRW	A B C D E	2,328
Big Mac	Oat	A B C D E F	2,279
Duster	HRW	A B C D E F	2,271
TAM Soft 700	SRW	A B C D E F G	2,144
USG 3555	SRW	A B C D E F G H	2,079
Coronado	HRW	B C D E F G H	2,047
Coker 9553	SRW	B C D E F G H I	1,975
RAM 99016	Oat	B C D E F G H I	1,943
Bob	Oat	B C D E F G H I	1,933
TAM 111	HRW	B C D E F G H I	1,928
Pete	HRW	B C D E F G H I J	1,860
Deliver	HRW	B C D E F G H I J	1,852
Endurance	HRW	B C D E F G H I J	1,841
Heavy Grazer TX 7306	SRW	C D E F G H I J K	1,777
Armour	HRW	D E F G H I J K L	1,722
Weathermaster 135	HRW	D E F G H I J K L	1,671
Horizon 201	Oat	D E F G H I J K L M	1,621
Shocker	HRW	D E F G H I J K L M	1,611
Bullet	HRW	E F G H I J K L M	1,574
Jagalene	HRW	E F G H I J K L M	1,509
TAM 401	HRW	E F G H I J K L M	1,490
Fuller	HRW	E F G H I J K L M	1,481
Magnolia	SRW	E F G H I J K L M	1,472
Jackpot	HRW	F G H I J K L M	1,364
Greer	HRW	G H I J K L M	1,345
TAMO 406	Oat	G H I J K L M	1,309
Jagger	HRW	G H I J K L M	1,265
Santa Fe	HRW	H I J K L M	1,190
TAMO 606	Oat	I J K L M	1,093
TAM 203	HRW	J K L M	1,006
LA 99017	Oat	J K L M	1,001
Horizon 270	Oat	K L M	871
Harrison	Oat	L M	811
Sturdy 2K	HRW	M	743
		Mean	**1,750**
		CV,%	**30.2**

† HRW, hard red winter wheat; SRW, soft red winter wheat.

‡ Means preceded by the same letter within a column are not significantly different according to Duncan's Multiple Range Test (P = 0.05).

Table 3. Mean early season forage yield at the Brazos Bottom, College Station, TX in 2012.

Cultivar	Type†	Duncan Grouping ‡	Forage Yield kg ha^{-1}
Pete	HRW	A	5,762
Bullet	HRW	A B	5,718
Fuller	HRW	A B C	5,492
Coker 9553	SRW	A B C D	5,392
Endurance	HRW	A B C D	5,310
Coronado	HRW	A B C D	5,296
Magnolia	SRW	A B C D	5,292
Doans	HRW	A B C D E	5,261
TAM 111	HRW	A B C D E F	5,037
Weathermaster 135	HRW	A B C D E F	4,929
Fannin	HRW	A B C D E F	4,742
Jagger	HRW	A B C D E F	4,721
Jackpot	HRW	A B C D E F	4,652
Santa Fe	HRW	A B C D E F	4,592
Jagalene	HRW	A B C D E F	4,581
TAM 401	HRW	A B C D E F	4,537
Sturdy 2K	HRW	A B C D E F	4,525
Bob	Oat	A B C D E F G	4,457
Heavy Grazer TX 7306	SRW	A B C D E F G	4,334
Shocker	HRW	A B C D E F G	4,328
Heavy Grazer 76-30	Oat	A B C D E F G	4,284
TAMO 406	Oat	A B C D E F G	4,263
LA 841	SRW	A B C D E F G	4,246
Duster	HRW	A B C D E F G	4,245
Billings	HRW	A B C D E F G	4,162
Horizon 270	Oat	A B C D E F G	4,156
Harrison	Oat	A B C D E F G	4,012
Deliver	HRW	A B C D E F G	4,008
TAM Soft 700	SRW	A B C D E F G	3,989
Greer	HRW	A B C D E F G	3,972
Horizon 201	Oat	A B C D E F G	3,933
TAM 304	HRW	B C D E F G	3,876
TAM 112	HRW	C D E F G	3,732
Armour	HRW	C D E F G	3,636
USG 3555	SRW	D E F G	3,630
TAM 203	HRW	E F G	3,432
RAM 99016	Oat	F G	3,403
TAMO 606	Oat	G	2,690
		Mean	**4,435**
		CV,%	**23.5**

† HRW, hard red winter wheat; SRW, soft red winter wheat.

‡ Means preceded by the same letter within a column are not significantly different according to Duncan's Multiple Range Test (P = 0.05).

Table 4. Mean late season forage yield at the Brazos Bottom, College Station, TX in 2011.

Cultivar	Type†	Duncan Grouping ‡	Forage Yield kg ha^{-1}
Sturdy 2K	HRW	A	2,415
Coronado	HRW	A B	2,266
Santa Fe	HRW	A B C	2,219
Doans	HRW	A B C D	2,177
Magnolia	SRW	A B C D	2,165
RAM 99016	Oat	A B C D E	2,113
Shocker	HRW	A B C D E	2,108
TAM 203	HRW	A B C D E F	2,051
TAM 401	HRW	A B C D E F G	2,035
Weathermaster 135	HRW	A B C D E F G	2,029
LA 841	SRW	A B C D E F G	1,969
USG 3555	SRW	A B C D E F G H	1,950
TAMO 606	Oat	A B C D E F G H	1,919
TAM 304	HRW	A B C D E F G H	1,880
LA 99017	Oat	A B C D E F G H	1,840
Horizon 201	Oat	A B C D E F G H	1,808
Jagger	HRW	A B C D E F G H	1,804
Fuller	HRW	A B C D E F G H	1,799
Heavy Grazer 76-30	Oat	A B C D E F G H	1,789
Harrison	Oat	A B C D E F G H	1,750
Big Mac	Oat	A B C D E F G H	1,731
Fannin	HRW	A B C D E F G H	1,721
Greer	HRW	A B C D E F G H	1,718
Billings	HRW	B C D E F G H	1,659
Endurance	HRW	B C D E F G H	1,639
Horizon 270	Oat	B C D E F G H	1,616
TAM 111	HRW	B C D E F G H	1,606
TAM 112	HRW	B C D E F G H	1,595
Pete	HRW	B C D E F G H	1,564
Coker 9553	SRW	B C D E F G H	1,554
Armour	HRW	C D E F G H	1,526
TAMO 406	Oat	C D E F G H	1,513
Heavy Grazer TX 7306	SRW	D E F G H	1,503
Duster	HRW	D E F G H	1,467
TAM Soft 700	SRW	D E F G H	1,466
Bob	Oat	E F G H	1,405
Jackpot	HRW	F G H	1,387
Bullet	HRW	F G H	1,348
Jagalene	HRW	G H	1,322
Deliver	HRW	H	1,241
		Mean	**1,766**
		CV,%	**22.9**

† HRW, hard red winter wheat; SRW, soft red winter wheat.

‡ Means preceded by the same letter within a column are not significantly different according to Duncan's Multiple Range Test (P = 0.05).

Table 5. Mean late season forage yield at the Brazos Bottom, College Station, TX in 2012.

Cultivar	Type†	Duncan Grouping ‡	Forage Yield kg ha^{-1}
TAM 401	HRW	A	3,490
USG 3555	SRW	A B	3,428
Santa Fe	HRW	A B C	3,350
Pete	HRW	A B C D	3,232
Fuller	HRW	A B C D	3,184
Heavy Grazer TX 7306	SRW	A B C D	3,152
TAM 111	HRW	A B C D	3,132
Coker 9553	SRW	A B C D E	3,054
Jagalene	HRW	A B C D E	3,021
LA 841	SRW	A B C D E	2,970
Duster	HRW	A B C D E F	2,900
Shocker	HRW	A B C D E F G	2,876
TAM Soft 700	SRW	A B C D E F G	2,866
TAM 304	HRW	A B C D E F G	2,858
RAM 99016	Oat	A B C D E F G	2,831
Jagger	HRW	A B C D E F G H	2,772
Doans	HRW	A B C D E F G H	2,739
Greer	HRW	A B C D E F G H	2,727
TAM 112	HRW	A B C D E F G H	2,672
Sturdy 2K	HRW	A B C D E F G H	2,553
Weathermaster 135	HRW	A B C D E F G H I	2,508
Billings	HRW	A B C D E F G H I	2,488
Magnolia	SRW	A B C D E F G H I	2,479
Coronado	HRW	A B C D E F G H I	2,469
Bullet	HRW	A B C D E F G H I	2,461
Fannin	HRW	A B C D E F G H I	2,388
TAMO 606	Oat	A B C D E F G H I	2,376
TAM 203	HRW	A B C D E F G H I	2,327
Jackpot	HRW	B C D E F G H I	2,191
Endurance	HRW	C D E F G H I	2,182
Deliver	HRW	C D E F G H I	2,149
Armour	HRW	C D E F G H I	2,129
Heavy Grazer 76-30	Oat	D E F G H I	2,015
TAMO 406	Oat	E F G H I	1,886
Harrison	Oat	F G H I	1,712
Horizon 201	Oat	G H I	1,656
Horizon 270	Oat	H I	1,579
Bob	Oat	I	1,323
		Mean	**2,582**
		CV,%	**27.2**

† HRW, hard red winter wheat; SRW, soft red winter wheat.

‡ Means preceded by the same letter within a column are not significantly different according to Duncan's Multiple Range Test (P = 0.05).

Table 6. Mean early and late season mean dry matter yield at the Brazos Bottom, College Station, TX in 2011 and 2012.

	Forage Yield			
	2011		2012	
Type †	Early Season ‡	Late Season §	Early Season	Late Season
	kg ha^{-1}			
SRW	1,968 a¶	1,767 a	4,480 a	2,991 a
HRW	1,774 ab	1,774 a	4,606 a	2,699 a
Oat	1,560 b	1,747 a	3,899 b	1,922 b
Mean	1,750	1,766	4,435	2,582
CV,%	40.3	25.9	24.9	28.2

† HRW, hard red winter wheat; SRW, soft red winter wheat.

‡ Dry matter yield prior to December 15.

§ Dry matter yield after December 15.

¶ Means followed by the same letter in a column are not significantly different according to Duncan's Multiple Range Test (P = 0.05).

Total dry matter production means were much lower in 2011 than in 2012, with means of 2222 and 6061 kg ha^{-1}, respectively. Severe drought conditions persisted throughout the 2011 season greatly reducing forage yield at all locations. In 2012, conditions were abnormally dry from planting until December, reducing early season forage production. Rainfall amounts returned to near average after this point with record rainfall in February and March (National Weather Service, 2012a).

Across all locations and years, there were no statistically significant differences in total dry matter production between cultivars (P=0.29). Great differences in environmental conditions between locations and years were evident with significant effects of environment (P<0.01) and significant environment by cultivar interaction (P<0.01). Means ranged from 908 kg ha^{-1} at McGregor in 2011 to 7010 kg ha^{-1} at the Brazos Bottom in 2012. When tests were not combined by location and year, significant differences between cultivars were seen at ASTREC in 2011 (P<0.05), McGregor in 2011 (P<0.01), and at the Brazos Bottom in both 2011 (P<0.01) and 2012 (P<0.01). At McGregor in 2012, no significant differences in dry matter production were seen (P=0.1) according to ANOVA. All total forage yield means with Duncan mean separations (P=0.05) are presented below in Tables 7 to 11 below.

When comparisons were made between the two classes of wheat and oat, significant differences in total dry matter production were observed only at the Brazos Bottom location in 2012 (P<0.01), where both classes of wheat produced significantly more biomass than did oat (Table 12).

Table 7. Mean total forage yield at ASTREC§, College Station, TX in 2011.

Cultivar	Type †	Duncan Grouping ‡				Forage Yield kg ha^{-1}
Santa Fe	HRW	A				3,648
Shocker	HRW	A	B			3,350
TAMO 606	Oat	A	B			3,339
Jagalene	HRW	A	B	C		3,248
Horizon 270	Oat	A	B	C		3,218
TAM 304	HRW	A	B	C		3,075
TAM 401	HRW	A	B	C	D	2,742
Horizon 201	Oat	A	B	C	D	2,624
Billings	HRW	A	B	C	D	2,519
LA 841	SRW	A	B	C	D	2,511
Big Mac	Oat	A	B	C	D	2,411
Pete	HRW	A	B	C	D	2,354
Fannin	HRW	A	B	C	D	2,349
TAM Soft 700	SRW	A	B	C	D	2,344
Duster	HRW	A	B	C	D	2,331
LA 99017	Oat	A	B	C	D	2,323
Heavy Grazer TX 7306	SRW	A	B	C	D	2,310
USG 3555	SRW	A	B	C	D	2,269
Heavy Grazer 76-30	Oat	A	B	C	D	2,257
Coronado	HRW	A	B	C	D	2,219
Harrison	Oat	A	B	C	D	2,212
TAM 112	HRW	A	B	C	D	2,164
Magnolia	SRW	A	B	C	D	2,120
Bullet	HRW		B	C	D	2,104
TAM 203	HRW		B	C	D	2,080
Bob	Oat		B	C	D	2,057
Greer	HRW		B	C	D	2,029
Jackpot	HRW		B	C	D	2,008
RAM 99016	Oat		B	C	D	1,971
TAM 111	HRW		B	C	D	1,909
Endurance	HRW		B	C	D	1,862
Fuller	HRW		B	C	D	1,815
Sturdy 2K	HRW			C	D	1,766
Deliver	HRW			C	D	1,746
Jagger	HRW			C	D	1,698
Coker 9553	SRW				D	1,459
Armour	HRW				D	1,442
Doans	HRW				D	1,438
TAMO 406	Oat				D	1,436
Weathermaster 135	HRW				D	1,368
				Mean		**2,242**
				CV,%		**38.2**

† HRW, hard red winter wheat; SRW, soft red winter wheat.

‡ Means preceded by the same letter within a column are not significantly different according to Duncan's Multiple Range Test (P = 0.05).

§ ASTREC, Animal Science, Teaching, Research, and Extension Complex.

Table 8. Mean total forage yield at the Brazos Bottom, College Station, TX in 2011.

Cultivar	Type †	Duncan Grouping ‡	Forage Yield kg ha^{-1}
Doans	HRW	A	5,122
Heavy Grazer 76-30	Oat	A B	4,527
Fannin	HRW	A B C	4,407
LA 841	SRW	A B C D	4,335
Coronado	HRW	A B C D E	4,312
TAM 304	HRW	A B C D E F	4,223
TAM 112	HRW	A B C D E F G	4,111
RAM 99016	Oat	A B C D E F G H	4,057
USG 3555	SRW	A B C D E F G H	4,029
Big Mac	Oat	A B C D E F G H	4,010
Billings	HRW	A B C D E F G H I	3,988
Duster	HRW	B C D E F G H I J	3,737
Shocker	HRW	B C D E F G H I J	3,720
Weathermaster 135	HRW	B C D E F G H I J	3,701
Magnolia	SRW	B C D E F G H I J	3,637
TAM Soft 700	SRW	B C D E F G H I J	3,610
TAM 111	HRW	B C D E F G H I J	3,533
Coker 9553	SRW	B C D E F G H I J	3,529
TAM 401	HRW	B C D E F G H I J	3,525
Endurance	HRW	B C D E F G H I J	3,479
Horizon 201	Oat	B C D E F G H I J	3,430
Pete	HRW	B C D E F G H I J	3,424
Santa Fe	HRW	B C D E F G H I J	3,409
Bob	Oat	B C D E F G H I J	3,339
Fuller	HRW	B C D E F G H I J	3,280
Heavy Grazer TX 7306	SRW	B C D E F G H I J	3,280
Armour	HRW	C D E F G H I J	3,248
Sturdy 2K	HRW	C D E F G H I J	3,158
Deliver	HRW	D E F G H I J	3,093
Jagger	HRW	E F G H I J	3,068
Greer	HRW	E F G H I J	3,062
TAM 203	HRW	E F G H I J	3,056
TAMO 606	Oat	F G H I J	3,013
Bullet	HRW	G H I J	2,922
LA 99017	Oat	H I J	2,841
Jagalene	HRW	H I J	2,831
TAMO 406	Oat	H I J	2,822
Jackpot	HRW	I J	2,751
Harrison	Oat	J	2,561
Horizon 270	Oat	J	2,487
		Mean	**3,516**
		CV,%	**20.2**

† HRW, hard red winter wheat; SRW, soft red winter wheat.

‡ Means preceded by the same letter within a column are not significantly different according to Duncan's Multiple Range Test (P = 0.05).

Table 9. Mean total forage yield at the Brazos Bottom, College Station, TX in 2012.

Cultivar	Type †	Duncan Grouping ‡	Forage Yield kg ha^{-1}
Pete	HRW	A	8,994
Fuller	HRW	A B	8,677
Coker 9553	SRW	A B C	8,446
Bullet	HRW	A B C	8,180
TAM 401	HRW	A B C D	8,027
Doans	HRW	A B C D	7,999
TAM 111	HRW	A B C D	7,970
Santa Fe	HRW	A B C D	7,942
Magnolia	SRW	A B C D E	7,772
Coronado	HRW	A B C D E	7,766
Jagalene	HRW	A B C D E	7,601
Jagger	HRW	A B C D E	7,493
Endurance	HRW	A B C D E	7,491
Heavy Grazer TX 7306	SRW	A B C D E	7,486
Weathermaster 135	HRW	A B C D E	7,437
LA 841	SRW	A B C D E F	7,217
Shocker	HRW	A B C D E F	7,204
Duster	HRW	A B C D E F	7,144
Fannin	HRW	A B C D E F	7,130
Sturdy 2K	HRW	A B C D E F	7,078
USG 3555	SRW	A B C D E F	7,057
TAM Soft 700	SRW	A B C D E F	6,855
Jackpot	HRW	A B C D E F	6,843
TAM 304	HRW	A B C D E F	6,734
Greer	HRW	A B C D E F	6,699
Billings	HRW	A B C D E F	6,669
TAM 112	HRW	B C D E F	6,404
Heavy Grazer 76-30	Oat	C D E F	6,298
RAM 99016	Oat	C D E F	6,234
Deliver	HRW	C D E F	6,157
TAMO 406	Oat	C D E F	6,149
Bob	Oat	D E F	5,779
Armour	HRW	D E F	5,765
TAM 203	HRW	D E F	5,759
Horizon 270	Oat	D E F	5,735
Harrison	Oat	D E F	5,724
Horizon 201	Oat	E F	5,589
TAMO 606	Oat	F	5,066
		Mean	**7,010**
		CV,%	**18.7**

† HRW, hard red winter wheat; SRW, soft red winter wheat.

‡ Means preceded by the same letter within a column are not significantly different according to Duncan's Multiple Range Test (*P* = 0.05).

Table 10. Mean total forage yield at McGregor, TX in 2011.

Cultivar	Type †	Duncan Grouping ‡	Forage Yield kg ha^{-1}
Heavy Grazer TX 7306	SRW	A	1,470
Billings	HRW	A B	1,392
Heavy Grazer 76-30	Oat	A B C	1,350
TAM 112	HRW	A B C D	1,314
Big Mac	Oat	A B C D E	1,148
TAM 401	HRW	A B C D E F	1,108
TAM 304	HRW	A B C D E F	1,095
RAM 99016	Oat	A B C D E F	1,067
Coker 9553	SRW	A B C D E F	1,061
Fuller	HRW	A B C D E F	1,058
LA 841	SRW	A B C D E F	1,054
Doans	HRW	A B C D E F	1,049
Fannin	HRW	A B C D E F	1,035
Coronado	HRW	A B C D E F	986
USG 3555	SRW	A B C D E F	985
TAMO 606	Oat	A B C D E F	957
Magnolia	SRW	A B C D E F	954
Duster	HRW	A B C D E F	949
TAM 203	HRW	A B C D E F	947
Jagger	HRW	A B C D E F	910
Bob	Oat	A B C D E F	908
Jackpot	HRW	A B C D E F	895
Greer	HRW	A B C D E F	873
Horizon 201	Oat	B C D E F	858
Shocker	HRW	B C D E F	853
Jagalene	HRW	B C D E F	824
LA 99017	Oat	C D E F	754
Santa Fe	HRW	D E F	747
Harrison	Oat	E F	696
Weathermaster 135	HRW	E F	694
Pete	HRW	E F	683
TAM 111	HRW	E F	676
Armour	HRW	E F	671
Deliver	HRW	E F	667
TAMO 406	Oat	E F	666
Endurance	HRW	E F	658
TAM Soft 700	SRW	E F	652
Sturdy 2K	HRW	E F	609
Bullet	HRW	E F	540
Horizon 270	Oat	F	518
		Mean	**908**
		CV,%	**37.7**

† HRW, hard red winter wheat; SRW, soft red winter wheat.

‡ Means preceded by the same letter within a column are not significantly different according to Duncan's Multiple Range Test (P = 0.05).

Table 11. Mean total forage yield at McGregor, TX in 2012.

Cultivar	Type †	Duncan Grouping ‡				Forage Yield kg ha^{-1}
Jagalene	HRW	A				6,662
Greer	HRW	A				6,445
Bullet	HRW	A	B			6,407
Fuller	HRW	A	B	C		6,216
Deliver	HRW	A	B	C		6,143
RAM 99016	Oat	A	B	C		6,107
Jackpot	HRW	A	B	C		6,036
Billings	HRW	A	B	C		6,027
Magnolia	SRW	A	B	C		5,916
Horizon 270	Oat	A	B	C		5,659
Pete	HRW	A	B	C		5,582
USG 3555	SRW	A	B	C		5,545
LA 841	SRW	A	B	C		5,450
Fannin	HRW	A	B	C		5,417
Heavy Grazer 76-30	Oat	A	B	C		5,381
TAM 401	HRW	A	B	C		5,357
Armour	HRW	A	B	C		5,350
Duster	HRW	A	B	C		5,341
TAM 304	HRW	A	B	C	D	5,214
Bob	Oat	A	B	C	D	5,129
TAM Soft 700	SRW	A	B	C	D	5,019
Harrison	Oat	A	B	C	D	5,001
TAMO 606	Oat	A	B	C	D	4,857
Horizon 201	Oat	A	B	C	D	4,658
Coronado	HRW	A	B	C	D	4,577
Shocker	HRW	A	B	C	D	4,561
Coker 9553	SRW	A	B	C	D	4,538
TAMO 406	Oat	A	B	C	D	4,513
Heavy Grazer TX 7306	SRW	A	B	C	D	4,472
Endurance	HRW	A	B	C	D	4,461
Sturdy 2K	HRW	A	B	C	D	4,456
Weathermaster 135	HRW	A	B	C	D	4,448
Santa Fe	HRW	A	B	C	D	4,322
TAM 112	HRW	A	B	C	D	4,305
Jagger	HRW	A	B	C	D	4,137
Doans	HRW		B	C	D	3,902
TAM 203	HRW			C	D	3,824
TAM 111	HRW				D	2,812
				Mean		**5,112**
				CV,%		**27.3**

† HRW, hard red winter wheat; SRW, soft red winter wheat.

‡ Means preceded by the same letter within a column are not significantly different according to Duncan's Multiple Range Test (P = 0.05).

Table 12. Mean total forage yield by class and species at the Brazos Bottom, College Station, TX in 2011 and 2012.

Type †	Forage Yield 2011	Forage Yield 2012
	kg ha^{-1}	
SRW	3,736 a‡	7,472 a
HRW	3,548 ab	7,297 a
Oat	3,308 b	5,821 b
Mean	3,516	7,010
CV,%	24	19.2

† HRW, hard red winter wheat; SRW, soft red winter wheat.

‡ Means followed by the same letter in a column are not significantly different using Duncan's Multiple Range Test (P = 0.05).

Forage Nutritive Value

Forage nutritive value data was taken on forage samples from experiments in the Brazos Bottom both years and from McGregor in 2012. Nutritive value data for the Brazos Bottom in 2011 is from wheat only. It was initially determined that a single NIR calibration equation could only accurately predict nutritive values for a single species. Subsequently a subset of oat forages were tested and added to the NIR prediction equation. Results were accurate and did not compromise the overall accuracy of the equation thus oat forages were tested along with wheat in 2012. Forage nutritive value is a dynamic continuum, changing with time (Redmon, 2011). The results presented on nutritive value represent only a few points on this continuum and should be interpreted as such. As a benchmark, nutrient requirements for growing steers and heifers are provided in Table 13.

Table 13. Nutrient requirements and maximum tolerable concentrations for growing steer and heifer calves based on average daily gain goals. † ‡

Average Daily Gain	Dry Matter Intake	Total Digestible Nutrients	Crude Protein	P	K	Ca	Mg
kg day^{-1}		% of Dry Matter					
0.74	5.28	64	12.1	0.24	0.6	0.5	0.1
0.99	5.28	69	14.1	0.29	0.6	0.62	0.1
1.23	5.24	75	16.3	0.34	0.6	0.75	0.1
1.48	5.04	83	19	0.41	0.6	0.9	0.1
Maximum Tolerable Concentration		–	–	–	3	–	0.4

† Based on a 198 kg steer or heifer calf with a mature body weight of 543 kg at 28% fat.

‡ Adapted from Gadberry (2001) based on National Research Council (1996).

Total Digestible Nutrients

Total digestible nutrient content (TDN) among cultivars was different in the early cuttings both years at the Brazos Bottom ($P<0.01$), but these differences were not observed at the late cutting dates or at McGregor. In 2011, mean TDN values at the Brazos Bottom were 65.8% and 60.3% for early and late cuttings, respectively. We would typically expect to see such a trend, where forage digestibility declines with increasing maturity and cell wall lignification. However, in 2012 TDN means were opposite the trend of the previous year with 59.8% and 65% for early and late cuttings, respectively. Dilution caused by rapid forage growth and nutrient uptake following winter dormancy caused by favorable conditions may be responsible for this deviation from the expected outcome. Cultivar nutritive value means for each cutting at the Brazos Bottom can be found in Tables 14-17 below.

The range of means for TDN content at McGregor was very similar to that of the late cutting at the Brazos Bottom in 2012, yielding a range of 64.6 – 68.6%, which was harvested 14 days later. According to the information in Table 13 (Gradberry) all cultivars at this location produced forages with TDN values sufficient to yield 0.74 kg in average daily gains, assuming no other limitations. Cultivar means for nutritive value for McGregor can be found in Table 18. The similarity between TDN values at these two locations, which were harvested only 14 days apart, suggests that maturity and environmental conditions have a substantial effect on TDN content of small grains. No cultivars tested consistently exhibited TDN values within the upper quartile, with the near exception of TAM401 (PI 658500), which consistently performed well at the Brazos Bottom.

When analyzed by small grain species and class, few differences were observed. At McGregor in 2012, TDN values for SRW (67.3%) and HRW (67%) were significantly higher than oat (65.59%) at a 5% level of significance. These findings were not consistent with those from the Brazos Bottom, where oat had the highest mean TDN in both early and late season cuttings but was only significantly higher than SRW in the early cutting.

It should be noted that no significant differences in IVDMD were seen between cultivars at any location. This being said, IVDMD grand means at each location were consistently around 10% higher than corresponding TDN value. IVDMD is considered to be a better measure of digestibility because it mimics the environment present in the rumen. This discrepancy between digestibility measures indicated that the equation used to calculate TDN may need to be amended to yield values that closer represent those of IVDMD. We did find that in 2012 at the Brazos Bottom, mean IVDMD for oat (71.22%) was significantly higher than HRW (68.07%) and SRW (66.6%) in the early cutting. In the later cutting, oat and SRW IVDMD values (75.62% and 75.13%) were significantly higher than that of HRW (73.16%). At McGregor in 2012, mean IVDMD was 80.32% with no differences observed between species.

Table 14. Mean early season nutritive values at the Brazos Bottom, College Station, TX, in 2011.

		TDN‡	CP	P	K	Ca	Mg
Cultivar	**Type†**	**% of Dry Matter**					
TAM 203	HRW	67.87	20.36	0.27	2.60	0.77	0.25
Santa Fe	HRW	67.54	19.66	0.26	2.65	0.73	0.25
Fuller	HRW	67.21	19.87	0.26	2.55	0.76	0.26
Armour	HRW	67.02	18.41	0.26	2.67	0.73	0.23
USG 3555	SRW	66.98	19.27	0.24	2.56	0.81	0.27
TAM 401	HRW	66.83	18.80	0.24	2.51	0.73	0.25
Weathermaster 135	HRW	66.59	19.20	0.26	2.65	0.79	0.25
Greer	HRW	66.47	19.19	0.26	2.43	0.82	0.29
Heavy Grazer TX 7306	SRW	66.44	17.82	0.24	2.54	0.77	0.24
Bullet	HRW	66.39	18.69	0.22	2.59	0.80	0.27
Jackpot	HRW	66.37	18.68	0.25	2.56	0.77	0.26
Jagalene	HRW	66.35	18.87	0.25	2.49	0.81	0.27
Deliver	HRW	66.19	17.73	0.23	2.67	0.83	0.24
Sturdy 2K	HRW	66.13	19.83	0.26	2.64	0.86	0.31
Magnolia	SRW	65.93	18.77	0.24	2.48	0.90	0.31
Endurance	HRW	65.91	17.80	0.25	2.27	0.76	0.23
LA 841	SRW	65.83	18.17	0.25	2.47	0.85	0.28
Coker 9553	SRW	65.81	17.96	0.25	2.51	0.76	0.24
Pete	HRW	65.75	18.44	0.25	2.58	0.78	0.26
TAM 304	HRW	65.69	17.61	0.24	2.65	0.81	0.25
TAM Soft 700	SRW	65.57	16.74	0.22	2.26	0.79	0.27
Jagger	HRW	65.56	18.18	0.26	2.44	0.77	0.26
Coronado	HRW	65.55	18.29	0.25	2.59	0.74	0.26
Doans	HRW	65.03	17.52	0.22	2.60	0.79	0.28
TAM 112	HRW	65.01	16.75	0.23	2.52	0.80	0.26
Duster	HRW	64.71	17.26	0.24	2.55	0.79	0.27
TAM 111	HRW	64.69	15.81	0.23	2.59	0.77	0.26
Shocker	HRW	64.66	18.41	0.25	2.35	0.89	0.30
Fannin	HRW	63.87	15.60	0.22	2.44	0.71	0.28
Billings	HRW	62.73	15.99	0.23	2.41	0.87	0.27
	Mean	65.88	18.18	0.24	2.53	0.79	0.26
	CV,%	2.50	8.40	10.50	7.80	16.08	11.90
	LSD	2.35	2.15	0.04	0.28	0.18	0.04

† HRW, hard red winter wheat; SRW, soft red winter wheat.

‡ TDN= 81.38 + (CP x 0.36) - (ADF x 0.77)

Table 15. Mean early season forage nutritive values at the Brazos Bottom, College Station, TX in 2012.

		TDN‡	CP	P	K	Ca	Mg
Cultivar	Type†	% of Dry Matter					
Armour	HRW	63.37	20.24	0.35	2.59	0.71	0.31
TAM 304	HRW	62.60	19.45	0.35	2.38	0.80	0.30
RAM 99016	Oat	62.57	18.39	0.34	2.33	0.71	0.36
Jagalene	HRW	62.14	19.16	0.33	2.36	0.94	0.33
Greer	HRW	61.96	18.28	0.32	2.48	0.61	0.28
Bob	Oat	61.89	18.06	0.36	2.40	0.86	0.36
TAM 401	HRW	61.71	19.96	0.35	2.44	0.71	0.31
Heavy Grazer 76-30	SRW	61.35	17.95	0.33	2.48	0.69	0.34
Duster	HRW	61.31	18.75	0.34	2.42	0.73	0.31
TAM 112	HRW	61.11	19.32	0.35	2.48	0.83	0.33
TAMO 406	SRW	61.09	17.17	0.32	2.32	0.67	0.33
TAMO 606	Oat	61.02	18.86	0.36	2.38	0.82	0.40
Pete	HRW	60.89	18.80	0.32	2.30	0.83	0.32
LA 841	SRW	60.85	19.64	0.35	2.53	0.65	0.30
Horizon 201	Oat	60.38	17.78	0.34	2.27	0.94	0.39
Coronado	HRW	60.34	17.30	0.32	2.43	0.96	0.33
Santa Fe	HRW	60.24	18.27	0.34	2.42	0.97	0.37
Deliver	HRW	60.16	17.38	0.32	2.61	0.81	0.31
USG 3555	SRW	60.13	17.36	0.34	2.25	0.86	0.32
Harrison	Oat	60.08	16.77	0.32	2.28	0.89	0.39
Horizon 270	Oat	59.95	16.11	0.32	2.22	0.91	0.41
TAM Soft 700	Oat	59.90	17.89	0.32	2.54	0.72	0.32
Coker 9553	SRW	59.84	17.08	0.34	2.43	0.87	0.32
Heavy Grazer TX 7306	Oat	59.81	17.50	0.33	2.67	0.80	0.33
Jackpot	HRW	59.77	17.91	0.33	2.40	0.86	0.34
Shocker	HRW	59.58	18.74	0.36	2.32	0.82	0.36
Bullet	HRW	59.35	17.25	0.34	2.22	0.94	0.35
Billings	HRW	58.98	15.37	0.31	2.14	0.72	0.32
Doans	HRW	58.87	15.73	0.33	2.34	0.98	0.33
TAM 203	HRW	58.36	16.81	0.37	2.40	1.03	0.39
Jagger	HRW	58.08	16.41	0.35	2.36	1.06	0.38
TAM 111	HRW	57.95	16.39	0.33	2.39	0.97	0.36
Fannin	HRW	57.91	15.78	0.36	2.40	0.91	0.36
Endurance	HRW	57.79	15.33	0.34	2.33	0.96	0.35
Weathermaster 135	HRW	57.26	14.56	0.34	2.62	0.87	0.32
Sturdy 2K	HRW	56.80	14.20	0.32	2.16	1.11	0.38
Magnolia	SRW	56.00	14.48	0.33	2.27	1.18	0.42
Fuller	HRW	54.67	14.97	0.37	2.17	1.27	0.44
	Mean	59.80	17.40	0.34	2.38	0.87	0.35
	CV,%	4.85	12.10	8.89	9.33	31.16	17.60
	LSD	4.10	2.97	0.04	0.31	0.38	0.09

† HRW, hard red winter wheat; SRW, soft red winter wheat.

‡ TDN= 81.38 + (CP x 0.36) - (ADF x 0.77)

Table 16. Mean late season forage nutritive values at the Brazos Bottom, College Station, TX in 2011.

Cultivar	Type†	TDN‡	CP	P	K	Ca	Mg
		% of Dry Matter					
Magnolia	SRW	62.24	16.91	0.26	2.11	1.22	0.37
Shocker	HRW	62.23	16.90	0.29	2.13	1.13	0.33
Bullet	HRW	62.16	15.54	0.26	1.96	1.25	0.34
Deliver	HRW	62.00	16.38	0.27	2.19	1.22	0.33
Pete	HRW	61.83	16.11	0.27	2.06	1.11	0.32
Fuller	HRW	61.69	16.00	0.25	1.98	1.27	0.35
TAM 401	HRW	61.49	16.06	0.27	2.07	1.17	0.33
LA 841	SRW	61.40	15.81	0.26	2.12	1.27	0.36
Santa Fe	HRW	61.33	16.18	0.24	1.99	1.31	0.36
TAM 112	HRW	61.10	15.54	0.26	1.84	1.22	0.34
TAM 203	HRW	61.04	15.64	0.29	2.12	1.30	0.35
Jackpot	HRW	60.91	16.15	0.25	1.93	1.38	0.38
Armour	HRW	60.79	15.86	0.28	2.00	1.38	0.37
Coker 9553	SRW	60.73	14.81	0.26	1.81	1.34	0.37
Jagalene	HRW	60.70	15.25	0.26	2.01	1.38	0.38
TAM Soft 700	SRW	60.70	15.39	0.26	1.89	1.35	0.38
Coronado	HRW	60.64	15.69	0.26	2.21	1.11	0.34
Heavy Grazer TX 7306	SRW	60.60	14.65	0.25	2.04	1.22	0.33
Greer	HRW	60.49	14.64	0.26	1.88	1.34	0.36
Doans	HRW	60.20	13.72	0.22	1.91	1.39	0.37
Weathermaster 135	HRW	60.10	14.97	0.26	1.90	1.43	0.37
TAM 304	HRW	59.81	14.42	0.29	1.82	1.31	0.34
Duster	HRW	59.74	13.65	0.22	1.88	1.40	0.37
Jagger	HRW	59.62	14.14	0.28	1.99	1.30	0.37
Endurance	HRW	59.54	14.57	0.26	1.76	1.50	0.40
Billings	HRW	59.54	13.22	0.22	1.91	1.28	0.36
USG 3555	SRW	59.46	13.94	0.23	1.78	1.44	0.41
Sturdy 2K	HRW	59.46	14.69	0.22	1.95	1.60	0.43
TAM 111	HRW	58.83	13.99	0.25	1.85	1.58	0.40
Fannin	HRW	58.66	12.58	0.26	1.59	1.47	0.38
	Mean	60.63	15.11	0.26	1.96	1.32	0.36
	CV,%	3.83	13.40	13.70	15.09	20.40	14.30
	LSD	3.27	2.86	0.05	0.41	0.38	0.07

† HRW, hard red winter wheat; SRW, soft red winter wheat.

‡ TDN= 81.38 + (CP x 0.36) - (ADF x 0.77)

Table 17. Mean late season forage nutritive values at the Brazos Bottom, College Station, TX in 2012.

Cultivar	Type†	TDN‡	CP	P	K	Ca	Mg
		% of Dry Matter					
Harrison	Oat	68.69	25.30	0.38	2.52	0.62	0.30
TAMO 606	Oat	67.67	24.12	0.39	2.32	0.62	0.30
USG 3555	SRW	66.84	22.33	0.32	2.35	0.60	0.26
TAM Soft 700	SRW	66.45	22.02	0.34	2.53	0.56	0.26
Deliver	HRW	66.14	19.83	0.30	2.41	0.64	0.25
Fannin	HRW	66.11	21.41	0.36	2.37	0.68	0.27
TAM 112	HRW	66.10	22.36	0.40	2.54	0.73	0.26
LA 841	SRW	66.01	23.48	0.37	2.62	0.64	0.29
Fuller	HRW	65.50	20.59	0.34	2.27	0.81	0.31
TAM 401	HRW	65.49	23.06	0.38	2.50	0.63	0.28
Duster	HRW	65.47	20.02	0.31	2.42	0.64	0.25
Bob	Oat	65.38	23.27	0.38	2.40	0.77	0.34
TAM 203	HRW	65.26	20.57	0.36	2.57	0.65	0.26
Horizon 201	Oat	65.21	21.32	0.37	2.23	0.80	0.35
TAM 304	HRW	65.05	21.63	0.39	2.54	0.71	0.27
Jackpot	HRW	65.04	19.44	0.36	2.59	0.67	0.26
Horizon 270	Oat	64.91	20.30	0.33	2.09	0.81	0.39
Jagalene	HRW	64.85	20.11	0.36	2.40	0.82	0.28
Coronado	HRW	64.83	19.57	0.32	2.48	0.63	0.26
TAM 111	HRW	64.80	20.04	0.35	2.50	0.75	0.28
Heavy Grazer 76-30	Oat	64.79	20.37	0.33	2.27	0.80	0.33
Billings	HRW	64.68	19.18	0.31	2.23	0.61	0.26
Armour	HRW	64.65	20.73	0.34	2.49	0.70	0.25
Heavy Grazer TX 7306	SRW	64.47	19.77	0.35	2.30	0.70	0.27
Santa Fe	HRW	64.43	20.50	0.36	2.57	0.68	0.27
Coker 9553	SRW	64.32	18.92	0.32	2.23	0.72	0.28
Endurance	HRW	64.29	18.48	0.32	2.23	0.69	0.25
Shocker	HRW	64.24	22.28	0.37	2.50	0.76	0.31
Bullet	HRW	64.22	19.24	0.34	2.36	0.76	0.27
Sturdy 2K	HRW	64.19	19.00	0.29	2.32	0.68	0.30
TAMO 406	Oat	63.96	20.95	0.34	2.21	0.81	0.34
Jagger	HRW	63.92	19.58	0.36	2.39	0.70	0.28
Greer	HRW	63.83	20.52	0.37	2.40	0.64	0.27
Magnolia	SRW	63.76	17.96	0.31	2.37	0.68	0.30
Doans	HRW	63.69	17.71	0.30	2.15	0.68	0.27
RAM 99016	Oat	63.65	20.94	0.34	2.20	0.98	0.44
Pete	HRW	63.02	19.01	0.31	2.43	0.83	0.30
Weathermaster 135	HRW	62.91	18.04	0.34	2.40	0.72	0.25
	Mean	64.96	20.62	0.35	2.39	0.71	0.29
	CV,%	3.34	13.66	9.19	11.75	22.09	13.80
	LSD	3.05	3.95	0.04	0.39	0.22	0.06

† HRW, hard red winter wheat; SRW, soft red winter wheat.

‡ TDN= 81.38 + (CP x 0.36) - (ADF x 0.77)

Table 18. Mean forage nutritive values at McGregor, TX in 2012.

Cultivar	Type†	TDN‡	CP	P	K	Ca	Mg
		% of Dry Matter					
TAM 112	HRW	68.63	23.74	0.44	2.93	0.64	0.20
Coker 9553	SRW	68.55	22.50	0.42	2.95	0.55	0.19
Magnolia	SRW	68.50	23.55	0.41	2.91	0.59	0.19
TAM 304	HRW	67.98	22.65	0.42	2.84	0.61	0.20
Doans	HRW	67.76	23.06	0.42	2.90	0.63	0.19
Shocker	HRW	67.76	23.55	0.42	2.95	0.63	0.22
Sturdy 2K	HRW	67.76	22.03	0.40	3.01	0.53	0.19
USG 3555	SRW	67.71	21.57	0.39	2.80	0.63	0.19
Jagger	HRW	67.70	22.97	0.42	2.87	0.60	0.21
Coronado	HRW	67.68	24.09	0.44	2.95	0.68	0.23
TAM 203	HRW	67.62	24.21	0.46	3.06	0.56	0.21
Deliver	HRW	67.37	21.55	0.39	2.64	0.74	0.21
Fuller	HRW	67.24	21.84	0.38	2.64	0.67	0.23
Armour	HRW	67.22	23.70	0.43	2.84	0.65	0.21
Endurance	HRW	67.20	20.83	0.38	2.80	0.61	0.19
TAM 111	HRW	67.16	22.32	0.40	2.69	0.66	0.20
Fannin	HRW	67.11	21.32	0.40	2.77	0.58	0.19
Heavy Grazer TX 7306	SRW	67.05	24.19	0.43	2.93	0.57	0.21
TAM Soft 700	SRW	67.02	21.42	0.41	2.75	0.60	0.22
Pete	HRW	66.93	22.22	0.40	2.95	0.65	0.20
Santa Fe	HRW	66.52	22.12	0.41	2.85	0.63	0.22
TAMO 606	Oat	66.48	23.88	0.46	2.97	0.65	0.24
Weathermaster 135	HRW	66.47	23.42	0.44	3.02	0.67	0.23
Billings	HRW	66.44	21.35	0.39	2.69	0.66	0.21
Jackpot	HRW	66.43	20.32	0.37	2.58	0.75	0.22
Duster	HRW	66.42	21.47	0.40	2.80	0.62	0.20
TAM 401	HRW	66.40	21.44	0.40	2.70	0.61	0.20
Heavy Grazer 76-30	Oat	66.38	21.66	0.46	2.79	0.64	0.22
Harrison	Oat	66.27	22.96	0.45	2.79	0.58	0.22
Bullet	HRW	66.09	21.57	0.40	2.54	0.69	0.22
TAMO 406	Oat	66.08	22.20	0.46	2.90	0.57	0.21
Bob	Oat	65.98	22.22	0.47	2.98	0.61	0.23
Greer	HRW	65.83	22.25	0.39	2.81	0.64	0.21
RAM 99016	Oat	65.71	21.06	0.42	2.77	0.69	0.22
Horizon 201	Oat	65.61	22.33	0.45	2.76	0.61	0.22
LA 841	SRW	65.08	23.29	0.45	2.82	0.64	0.23
Horizon 270	Oat	64.87	19.00	0.38	2.49	0.66	0.23
Jagalene	HRW	64.69	19.67	0.37	2.46	0.76	0.22
	Mean	66.80	22.25	0.42	2.81	0.63	0.21
	CV,%	2.99	6.65	8.50	6.68	17.27	10.58
	LSD	2.80	2.08	0.05	0.26	0.15	0.03

† HRW, hard red winter wheat; SRW, soft red winter wheat.

‡ TDN= 81.38 + (CP x 0.36) - (ADF x 0.77)

Crude Protein

Significant differences in crude protein content (CP) were observed between wheat cultivars in the first cutting at the Brazos Bottom in 2011(P<0.01) and between all cultivars in 2012 (P<0.01). Cultivar means for early season forage CP content at this location ranged from 15.6% to 20.3% in 2011 and from 14.1% to 20.2% in 2012 (Tables 14 and 15). Differences in CP content may point to a lack of drought tolerance in cultivars with low CP contents. Sub-optimal root growth in dry conditions can limit N uptake, thereby reducing N concentration in plant tissue (Clarke, et al., 1990). These cultivars may also have a lower genetic potential for root growth and N uptake.

Differences in late season forage CP were only seen at the Brazos Bottom in 2012 (P<0.05) with means ranging from 17.71% to 25.29% (Table 17). Means were much lower for the late cutting in 2011, ranging from 12.58% to16.9% (Table 16). The low means and lack of difference between cultivars in 2011 can probably be attributed to limited irrigation and severe drought conditions that persisted through the 2011 growing season, hindering the potential for nitrogen uptake by wheat.

Differences in forage CP were also observed at McGregor in 2012 (P<0.01), with means ranging from 19% to 24.2% CP (Table 18). This range is very similar to the CP range for the later cutting at the Brazos Bottom, which again might suggest that environmental conditions and maturity have a profound effect on forage nutritive value. This agrees with the findings of Stewart, et al. (1981), where small grains forage N and K concentrations were influenced by average temperature.

Macronutrients

Forage macronutrients measured included P, K, Ca, and Mg. In the case of P, all cultivars at all locations contained sufficient P to produce 0.75 kg in average daily gains, with the exception of several cultivars in both cuttings at the Brazos Bottom in 2011 (Tables 14 and 16), including Billings (PI 656483) and Doans (AP02T4342) wheat. Significant differences in P content between cultivars were seen at the late cutting at the Brazos Bottom in 2012 (P<0.01) (Table 17) and at McGregor the same year (P<0.01) (Table 18). In regards to species and class of wheat, oat (0.44%) produced significantly higher forage P concentrations than did SRW (0.41%) and HRW (0.40%) at McGregor. Trends at the Brazos Bottom in the late cutting in 2012 were similar.

Forage K concentrations at all locations were well in excess of the 0.6% of dry matter required by growing steer and heifer calves (Gradberry, 2001). At McGregor in 2012, several varieties came near to or exceeded the maximum tolerable concentrations of forage P. Soil test P_2O_5 was very low at this location, thus we did not expect to find this inverse relationship between soil test P levels and tissue P concentrations. McGregor was also the only location to show significant differences in P concentration between cultivars (Table 18).

Mean forage Ca content for each cultivar at each location was also generally in excess of that required to achieve average daily gains of 1 kg day^{-1}. No significant differences in forage Ca content between cultivars were noted at any location. Significant differences were seen between species for the late cutting at the Brazos Bottom in 2012 (P<0.01) where oat (0.77%) mean forage Ca content was significantly higher than that of both HRW (0.70%) and SRW (0.65%). This trend was not observed at any other location.

Mg contents were well above requirements at all locations, with several varieties at the Brazos Bottoms reaching slightly above the maximum tolerable concentration of 0.40% on a dry matter basis. In 2012, significant differences between species were seen at all locations, with oat forage containing significantly higher Mg concentrations than did either class of wheat (Table 19).

Table 19. Mean forage Mg concentrations by species and class at College Station and McGregor, TX in 2012.

	Brazos Bottom		McGregor
Type †	Early Season ‡	Late Season §	
	Mg % of dry matter		
Oat	0.37a ¶	0.35a	0.22a
HRW	0.34b	0.27b	0.20b
SRW	0.33b	0.27b	0.20b
Mean	0.34	0.29	0.21
CV,%	18.3	14.9	10.8

† HRW, hard red winter wheat; SRW, soft red winter wheat.
‡ Dry matter yield prior to December 15.
§ Dry matter yield after December 15.
¶ Means followed by the same letter in a column are not significantly different according to Duncan's Multiple Range Test (P = 0.05).

Grain Yield

Grain yield was heavily influenced by environmental conditions. In 2011, severe drought conditions that persisted throughout the season coupled with a late freeze in the spring negatively impacted grain yield potential. In 2012, grain yield was much higher, as conditions vastly improved with a large amount of early spring precipitation (Tables 1 and 2). Leaf rust and lodging were problems seen as a result of prolonged wet conditions. Leaf rust and lodging were also observed in 2011, but to a lesser extent.

Significant differences in grain yield were seen between cultivars at each location (Tables 20 – 24). Data was not combined due to significant cultivar by environment interactions. Few similarities in cultivar performance between locations were seen, with the exception of Doans and Sturdy 2K (Marshall and Sutton, 2004). Doans performed well at all locations except at McGregor in 2012, where it still yielded higher than the average (Table 24). Sturdy 2K yielded very well at all locations under drought conditions experienced in 2011. In 2012 it yielded 2,300 to 2,400 kg ha^{-1} consistently. At both non-irrigated locations in 2011, HRW and SRW out yielded oat (P<0.05). At the irrigated location, oat had higher yield than SRW, and HRW was not significantly different from either oat or SRW. The following season, growing conditions were similar at the Brazos Bottom and McGregor, where rainfall was adequate to meet plant needs. At the Brazos Bottom, SRW (3,059 kg ha^{-1}) yielded significantly higher (P < 0.05) than oat (2,380 kg ha^{-1}) and HRW (2,198 kg ha^{-1}), and at McGregor, SRW (3,120 kg ha^{-1}) and oat (2,865 kg ha^{-1}) significantly (P < 0.05) out performed HRW (2,527 kg ha^{-1}).

Table 20. Mean grain yield and quality at ASTREC†, College Station, TX in 2011.

Cultivar	Type‡	Grain kg ha^{-1}	Test Weight kg m^{-3}	Protein %
TAM 304	HRW	1,616	737	13.98
Armour	HRW	1,502	735	13.03
Sturdy 2K	HRW	1,500	736	14.05
Doans	HRW	1,429	778	14.44
Coronado	HRW	1,312	747	13.10
Greer	HRW	1,307	725	14.33
Jackpot	HRW	1,307	748	14.66
Magnolia	SRW	1,285	728	13.52
TAM 112	HRW	1,266	762	12.80
LA 841	SRW	1,264	727	14.86
Fuller	HRW	1,261	746	14.62
Coker 9553	SRW	1,221	749	12.88
Duster	HRW	1,213	751	14.47
Billings	HRW	1,191	742	14.31
Santa Fe	HRW	1,181	752	14.82
Shocker	HRW	1,133	728	14.52
Fannin	HRW	1,125	760	14.07
Heavy Grazer TX 7306	SRW	1,114	709	13.33
TAM 401	HRW	1,104	723	14.66
Bullet	HRW	1,091	730	15.80
TAM 203	HRW	1,078	738	14.72
USG 3555	SRW	1,075	716	13.58
Jagger	HRW	1,067	743	15.22
Endurance	HRW	1,051	719	14.52
Jagalene	HRW	1,004	769	12.45
TAM Soft 700	SRW	985	725	13.53
TAM 111	HRW	896	747	15.22
Deliver	HRW	844	756	13.88
Weathermaster 135	HRW	831	727	14.20
Pete	HRW	705	742	13.95
TAMO 406	Oat	651	384	-
LA 99017	Oat	564	377	-
Harrison	Oat	544	384	-
RAM 99016	Oat	511	379	-
Horizon 201	Oat	320	-	-
Horizon 270	Oat	316	-	-
Bob	Oat	261	353	-
Heavy Grazer 76-30	Oat	249	372	-
TAMO 606	Oat	174	366	-
Big Mac	Oat	172	353	-
	Mean	1,009	704	14.11
	CV,%	22.5	2.05	8.48
	LSD	340	24	1.64

†ASTREC, Animal Science, Teaching, Research, and Extension Complex.

‡ HRW, hard red winter wheat; SRW, soft red winter wheat.

Table 21. Mean grain yield, lodging, and quality means at the Brazos Bottom, College Station, TX in 2011.

Cultivar	Type†	Grain kg ha^{-1}	Lodging 1<10 scale‡	Test Weight kg m^{-3}	Protein %
Doans	HRW	2,520	1	806	12.88
Sturdy 2K	HRW	2,484	1	768	12.56
Duster	HRW	2,441	1	796	11.60
TAMO 406	Oat	2,418	1	394	-
Coker 9553	SRW	2,397	1.5	790	12.64
TAMO 606	Oat	2,343	1	371	-
LA 99017	Oat	2,284	1	397	-
Harrison	Oat	2,265	1	399	-
Fuller	HRW	2,158	3.5	791	12.91
TAM Soft 700	SRW	2,151	1	767	11.75
Horizon 270	Oat	2,107	1	378	-
Greer	HRW	2,100	1	766	12.68
Coronado	HRW	2,099	1	792	13.24
Pete	HRW	2,080	1	787	13.06
Horizon 201	Oat	2,078	1	372	-
TAM 203	HRW	2,064	1	772	13.13
TAM 112	HRW	2,045	4	795	12.09
Magnolia	SRW	2,015	1	764	12.12
Jagalene	HRW	2,000	3.5	801	12.49
Armour	HRW	1,916	2.5	764	12.12
Jackpot	HRW	1,912	1	771	13.29
RAM 99016	Oat	1,888	1	417	-
Shocker	HRW	1,866	1	772	13.51
TAM 304	HRW	1,839	1	786	12.62
TAM 111	HRW	1,802	1.5	782	13.36
Bob	Oat	1,734	1	395	-
Santa Fe	HRW	1,714	2.5	789	13.45
LA 841	SRW	1,692	1	779	12.66
Heavy Grazer 76-30	Oat	1,664	1	404	-
Weathermaster 135	HRW	1,641	1	717	14.05
Bullet	HRW	1,609	1.5	769	14.23
Deliver	HRW	1,588	1	790	12.81
TAM 401	HRW	1,582	1	765	13.48
Jagger	HRW	1,560	3.5	776	14.25
Endurance	HRW	1,531	5	764	12.96
USG 3555	SRW	1,526	1	749	13.87
Big Mac	Oat	1,395	1	392	-
Fannin	HRW	1,386	5	798	12.99
Billings	HRW	1,306	1	810	13.15
Heavy Grazer TX 7306	SRW	1,059	1	761	13.70
	Mean	1,906	1.57	681	12.90
	CV,%	12.48	61.59	1.44	4.60
	LSD	333	1.358	14	0.84

† HRW, hard red winter wheat; SRW, soft red winter wheat.

‡ 10, severe lodging; 1, little to no lodging.

Table 22. Mean grain yield, lodging, and quality at the Brazos Bottom, College Station, TX in 2012.

Cultivar	Type†	Grain kg ha^{-1}	Lodging 1<10 scale‡	Test Weight kg m^{-3}	Protein %
Horizon 201	Oat	3,834	4	436	-
TAM Soft 700	SRW	3,525	1.5	745	12.95
Coker 9553	SRW	3,428	1.5	795	12.24
USG 3555	SRW	3,320	1.5	749	12.86
Horizon 270	Oat	3,298	2	406	-
Doans	HRW	3,297	1	816	11.95
LA 841	SRW	3,296	1	770	12.58
TAM 203	HRW	3,046	2	749	12.50
RAM 99016	Oat	3,041	4	415	-
Magnolia	SRW	3,007	1	755	11.99
Armour	HRW	2,959	2	736	11.84
TAM 401	HRW	2,922	3.5	752	12.88
TAM 304	HRW	2,912	1	755	12.46
Shocker	HRW	2,833	3.5	757	12.63
TAMO 406	Oat	2,797	8	414	-
Duster	HRW	2,585	2	759	12.33
Fannin	HRW	2,581	3.5	792	13.66
Coronado	HRW	2,578	1	770	12.58
Billings	HRW	2,569	1.5	784	11.99
Deliver	HRW	2,468	4	790	11.95
Endurance	HRW	2,456	4	754	11.48
Sturdy 2K	HRW	2,340	2.5	758	11.65
TAMO 606	Oat	2,308	5	356	-
Greer	HRW	2,091	2.5	697	12.12
Fuller	HRW	2,055	3.5	752	13.11
Weathermaster 135	HRW	1,953	1	674	11.17
TAM 111	HRW	1,795	5.5	758	12.29
Heavy Grazer TX 7306	SRW	1,783	2	687	13.16
Jackpot	HRW	1,706	4	682	12.31
Harrison	Oat	1,602	6	384	-
Santa Fe	HRW	1,551	6.5	713	12.99
Pete	HRW	1,479	1.7	738	11.90
Bob	Oat	1,321	9	387	-
Bullet	HRW	1,148	7	733	12.42
TAM 112	HRW	1,143	9	723	12.71
Jagger	HRW	1,105	5	674	13.29
Jagalene	HRW	908	7	681	12.76
Heavy Grazer 76-30	Oat	839	9	367	-
	Mean	2,373	3.69	676	12.45
	CV,%	15	39.8	2.74	5.22
	LSD	513	2.07	26	0.96

† HRW, hard red winter wheat; SRW, soft red winter wheat.

‡ 10, severe lodging; 1, little to no lodging.

Table 23. Mean grain yield and quality at McGregor, TX in 2011.

Cultivar	Type†	Grain $kg\ ha^{-1}$	Test Weight $kg\ m^{-3}$	Protein %
Sturdy 2K	HRW	2,110	718	10.94
Endurance	HRW	2,058	733	12.17
TAM Soft 700	SRW	1,889	717	11.66
Pete	HRW	1,882	768	10.87
Coker 9553	SRW	1,858	738	11.91
TAM 304	HRW	1,750	711	11.75
Jackpot	HRW	1,686	715	12.19
Duster	HRW	1,652	742	12.06
Doans	HRW	1,634	743	12.38
Weathermaster 135	HRW	1,583	707	11.65
Shocker	HRW	1,556	733	12.18
Deliver	HRW	1,484	755	12.85
TAM 203	HRW	1,463	714	11.11
Fuller	HRW	1,455	732	12.57
Armour	HRW	1,439	723	10.95
Greer	HRW	1,434	693	11.83
TAM 111	HRW	1,409	743	12.36
Santa Fe	HRW	1,386	720	12.26
Magnolia	SRW	1,385	694	11.93
LA 841	SRW	1,336	712	11.51
USG 3555	SRW	1,324	733	13.61
Bullet	HRW	1,267	743	12.96
TAMO 606	Oat	1,258	384	-
Coronado	HRW	1,253	730	12.21
Horizon 201	Oat	1,205	373	-
TAM 401	HRW	1,185	689	12.59
TAMO 406	Oat	1,166	384	-
RAM 99016	Oat	1,142	388	-
Fannin	HRW	1,136	730	12.97
LA 99017	Oat	1,118	387	-
Jagalene	HRW	1,084	735	10.93
Jagger	HRW	1,046	709	12.08
Billings	HRW	1,041	739	11.80
Heavy Grazer TX 7306	SRW	1,031	710	12.31
Harrison	Oat	977	399	-
Horizon 270	Oat	965	379	-
Bob	Oat	932	366	-
Heavy Grazer 76-30	Oat	861	392	-
TAM 112	HRW	832	738	12.20
Big Mac	Oat	801	406	-
	Mean	1,351	665	12.00
	CV,%	14.01	1.96	7.13
	LSD	265	203	1.20

† HRW, hard red winter wheat; SRW, soft red winter wheat.

Table 24. Mean grain yield, lodging, and quality at McGregor, TX in 2012.

Cultivar	Type†	Grain kg ha^{-1}	Lodging 1<10 scale‡	Test Weight kg m^{-3}	Protein %
Horizon 201	Oat	3,915	7	517	-
TAM Soft 700	SRW	3,534	3.5	726	11.55
TAM 304	HRW	3,492	2	721	12.62
TAM 401	HRW	3,474	4	726	11.88
Coker 9553	SRW	3,391	1.5	758	12.06
Fannin	HRW	3,376	3	769	12.41
Billings	HRW	3,342	2.5	762	12.03
USG 3555	SRW	3,311	2.5	724	11.50
Magnolia	SRW	3,233	1	721	11.64
Armour	HRW	3,198	6	706	11.84
Shocker	HRW	3,162	3	750	12.08
TAMO 606	Oat	3,068	7	498	-
Fuller	HRW	2,974	3.5	751	11.69
Doans	HRW	2,974	5.5	773	12.47
Deliver	HRW	2,937	6.5	774	11.99
Duster	HRW	2,932	6	747	11.88
LA 841	SRW	2,931	2	711	11.97
RAM 99016	Oat	2,930	2.5	544	-
TAM 203	HRW	2,904	4.5	740	12.19
TAMO 406	Oat	2,836	8.5	542	-
Bob	Oat	2,740	9	488	-
Harrison	Oat	2,637	5.5	530	-
Endurance	HRW	2,630	8.5	719	11.81
Horizon 270	Oat	2,614	3	529	-
Coronado	HRW	2,515	4.5	733	11.65
Sturdy 2K	HRW	2,486	3.5	745	11.25
Weathermaster 135	HRW	2,465	4.5	685	12.12
Heavy Grazer TX 7306	SRW	2,321	6	695	-
Greer	HRW	2,288	5.5	687	11.72
Heavy Grazer 76-30	Oat	2,187	8.5	485	11.55
TAM 111	HRW	2,071	7.5	731	11.87
Pete	HRW	2,050	5	738	11.79
Jackpot	HRW	1,872	7	693	11.85
Santa Fe	HRW	1,841	8	712	11.92
Jagger	HRW	1,519	7.5	677	12.42
Jagalene	HRW	1,487	8.5	690	11.44
Bullet	HRW	1,344	8.5	705	12.46
TAM 112	HRW	1,327	9	689	11.45
	Mean	2,692	5.3	681	11.90
	CV,%	14	30.9	2.5	4.77
	LSD	524	2.29	24	0.80

† HRW, hard red winter wheat; SRW, soft red winter wheat.

‡ 10, severe lodging; 1, little to no lodging.

Lodging ratings were taken at the Brazos Bottom both years and at McGregor in 2012. All locations showed highly significant differences between cultivars for the extent of lodging (Tables 21, 22, and 24). The groups of cultivars that exhibited the most lodging were different between the two years, due to highly contrasting environmental conditions. Results were very similar at the Brazos Bottom (Tables 21 and 22) and McGregor in 2012 (Table 24), with varieties like TAM 112 wheat (PI 643143), and Bob (Collins and Jones, 1978) and Heavy Grazer 76-30 oat (PI 240082) consistently rated as highly lodged. Lodging was highly negatively correlated to grain yield at both the Brazos Bottom (r = -0.66, P<0.01) and McGregor (r = -0.61, P<0.01) in 2012.

Grain Quality

Significant differences between cultivars for test weight were seen at all locations (Tables 20 – 24). In 2011, HRW test weight means were significantly higher than those of SRW at all locations, and oat had relatively stable mean test weights (386 ± 12.8 kg m^{-3}) across locations. The Brazos Bottom location produced the highest test weights, due to the use of irrigation at this location when ASTREC and McGregor suffered persistent drought conditions that plagued the Southern U.S. that year (Table 21). In 2012, no significant differences were seen between HRW and SRW at either location, but oats at the two locations were drastically different. Mean oat test weight at McGregor was 514 kg m^{-3}, which is well over the 463 kg m^{-3} needed to be classified U.S. Grade No. 1 (USDA, 2004). Mean test weight at the Brazos Bottom was in the same range as those in 2011. Unusually high test weight may be as a result of environmental stress during yield determining growth stages (Feeks 3 and 5), limiting tillers and seed number per panicle, then particularly favorable conditions from grain fill to maturity.

Protein differed by environment and cultivar as well (Tables 20 - 24). In general, protein content seemed to be greatest in low yielding environments. The highest mean grain protein content, 14.1%, was observed at ASTREC in 2011 (Table 20), where the lowest grain yield was observed. Conversely, in 2012 at McGregor where yield was very high, mean protein content was the lowest observed at 11.9% (Table 24). Within environments, the same trend held true, with a few exceptions. While significant differences in grain protein content between wheat cultivars were observed at all locations, no differences were seen between classes of wheat, meaning variation within classes is greater than that between them.

CHAPTER IV

NITROGEN RATE AND TIMING EFFECT ON FORAGE PRODUCTION IN WINTER WHEAT

Introduction

Winter wheat has a special niche in the Southern Great Plains region. Although wheat is most commonly grown for grain in other parts of the country, Southern producers often utilize the highly nutritive forage produced in the fall, winter, and spring as a source of fodder for grazing animals when other forage resources are generally low in supply, nutritive value, and digestibility (Lyon, et al., 2001; Beck, et al., 2005). In this region, these cool-season annual forages are the primary source of herbage used to pasture growing beef cattle (Redmon, et al., 1995b) and provide farmers and ranchers with management options to increase the profitability of their enterprises. It is estimated that 30-80% of the total wheat acres planted in the southern Great Plains are grazed by cattle (*Bos ssp.*) at some point during the growing season (Carver, et al., 1991; Pinchak, et al., 1996). Texas, Oklahoma, and Kansas are the major producers in this area, with an annual mean of 8.66 million hectares planted (NASS, 2012a) and 2.6 million head pastured on these small grains swards annually (NASS, 2012b).

Wheat produces a valuable, high-quality forage capable of sustaining the nutrient requirements of all grazing animals, regardless of class or species (Horn, 1983). Crude protein content of wheat in its vegetative state is often in excess of 25 % (Croy, 1983b). When the crop is intended for use as forage only, it can be cut for the purpose of stored forage products such as hay or silage as it nears maturity, or grazed until regrowth ceases (graze-out). In these situations, forage production is much greater than in dual-purpose settings, since winter wheat dry matter accumulation is greatest during stem elongation and floral initiation (Daigger, et al., 1976). In some cases, total forage yield for graze-out pasture can be three times that of swards where grazing is terminated at first hollow stem (Donnelly and McMurphy, 1983).

Fertility management plays a major role in the performance of forage and grain production systems, as well as the performance of grazing animals. Soil levels of available N, P, and K, along with vital micronutrients can limit yield and nutritive value of the forage and grain produced(Stewart, et al., 1981; Edmisten, et al., 1998b). Of these, N is known to be the most commonly limiting nutrient in soils due to abundant plant use and the many mechanisms by which N is lost from the root zone (Donnelly and McMurphy, 1983). Due to limiting levels in most soils, it is also the most commonly applied. In a study conducted by Carter (1967), pre-plant applications of N fertilizer slowed seedling growth or caused embryo death and reduced stand establishment. Carter (1967) found that soil moisture was vitally important to seedling establishment when N fertilizers were applied. They found that when available soil moisture was at 20%, seedling mortality was significantly increased compared to instances when available soil moisture neared 70%. At 70% available soil moisture, N fertilizer had little effect on seedling establishment. The cost of N fertilizer has also increased drastically in recent years, almost tripling in price from 2002 to 2012 (ERS, 2012a) increasing the need for added N use efficiency.

Currently, the Texas A&M University Soil, Water, and Forage Testing Laboratory makes N rate recommendations for grazed winter wheat swards based upon the nominal categories of heavy, moderate, and light grazing intensity. To improve this managerial tool, N rate recommendations might be made based on a specific yield goal, which can then be converted into animal unit days. Many producers use this measure to determine stocking density. These facts suggested a need for additional research in the area of N fertility management in grazed winter wheat systems which would allow for enhanced efficiency of these systems in the Central Texas region by providing producers the information they need to make the most profitable management choices. To address this issue, research was initiated in several locations in Central Texas to determine the effect of N fertility on forage production in winter wheat.

Materials and Methods

Experimental Locations

This research was initiated at three locations in central Texas. The first was located in the Brazos River Flood Plain (Brazos Bottom) near Snook, TX at the Texas A&M AgriLife Extension Farm (30° 30’ N lat; 96° 25’ W long; 66 m elevation above sea level.) This location is a Belk clay soil (fine, mixed, thermic Entic Hapluderts) exhibiting 0 to 1 % slopes. These soils are well drained with very slow permeability and high water holding capacity. The soil capability classification is 3S for non-irrigated, but was irrigated both years of the study. The second experimental location near College

Station, TX at ASTREC (30° 33’ N lat; 96° 24’ W long; 83 m elevation above sea level.) The soil type is a Roboco loamy fine sand (loamy, siliceous, active, thermic Aquic Arenic Paleustalfs) with a 1 to 3 % slope, moderate drainage, and rapid permeability in the upper layer with slow permeability in the subsoil. Large or repeated rainfall events can lead to a perched water table 0.5 to 1 m from the soil surface. The soil capability classification is 2E for non-irrigated. The third location was near McGregor, TX at the Texas A&M Agriculture Research and Extension Center (31° 22´ N lat; 97° 27´ W long; 240 m elevation above sea level). Soil type is a Slidell clay (fine, montmorillonitic, thermic Udic Haplusterts) with a 0- to 2 % slope, very slow permeability, and a high water holding capacity. The soil capability subclass was 2E for dryland and none was irrigated (NRCS, 2012).

This experiment was initiated to evaluate the effect of N fertilizer rate on forage production of winter wheat. Fannin (PI 639231), a commercially available HRW wheat cultivar was used due to its frequent use in Central Texas. Experimental units 1.5 m wide and 4.5 m long were laid out in a split-plot randomized block design with each treatment replicated four times. Pre-plant N rate, here after referred to as PreN, served as the main plot with top-dress N rate, here after referred to as PostN, as the sub plot.

Production Practices

In mid- to late-August, plot areas were disked or plowed to prepare the seedbed. Prior to planting, several soil samples were taken at each location to a depth of 60 cm, split into depth ranges (0-15 cm, 15-30 cm, 30-60 cm, and 60-90 cm), and combined based on depth range. Composite soil samples were obtained from each study location and submitted to the Texas A&M Soil, Water, and Forage Testing Lab for analysis. Routine soil analysis and stratified soil nitrate analysis results can be found in Tables 25 and 26, respectively. Soils at each location were amended with triple super phosphate (0-46-0) if needed to meet specified soil test recommendations based on the 0-15 cm samples from each location. P fertilizer was applied with a calibrated pendulum-type spreader, then incorporated with harrows or with the wheat drill if applied directly before planting.

Table 25. Soil analysis results for samples in the upper 15cm of soils at College Station and McGregor, TX in 2011 and 2012.

Location†	Year	NO_3^-	P	K
			PPM	
ASTREC				
	2012	8	44	200
Brazos Bottom				
	2011	23	68	438
	2012	28	131	491
McGregor				
	2012	14	29	201

† ASTREC, Animal Science, Teaching, Research, and Extension Complex.

Table 26. Stratified soil profile analysis of NO_3^- content results from College Station and McGregor, TX in 2011 and 2012.

Location†	Year	15-30 cm	30-60 cm	60-90 cm
			PPM	
ASTREC				
	2012	13	11	-
Brazos Bottom				
	2011	12	6	5
	2012	19	12	-
McGregor				
	2012	5	6	-

† ASTREC, Animal Science, Teaching, Research, and Extension Complex.

PreN treatments were surface applied as UAN (32-0-0) using a calibrated hand boom immediately prior to seeding in mid- to late-September. PreN application rates were determined by crediting soil test nitrate-N in the upper 15 cm of the soil to the PreN rates (0, 45, 67, 90, and 112 kg ha^{-1}) established in the experimental protocol. The adjusted PreN rates can be seen in Table 27. PostN treatments (0, 22, 45, 67, and 90 kg ha^{-1}) were applied in the same manner following each forage harvest. PostN treatments were not adjusted for soil N concentration.

A seven row Hege 500 small plot drill (Hege Equipment Inc., Colwich, KS) with 16.5 cm row spacing was used to plant seed and incorporate surface applied UAN. The planter was equipped with a cone type seed-metering device calibrated to plant a plot 1.5 m in width and 6 m in length. After emergence of seedlings in the experimental units, 1.5 m alleyways between replications were seeded, yielding 1.5 m wide, 4.5 m long plots for evaluation. This was done to ensure uniform stands over the experimental unit and to reduce any edge affect that would have resulted from blank alleys.

All plots were seeded with Fannin treated with the label rate of Gaucho XT® to prevent seedling disease and early-season insect damage. All plots were seeded at the rate of 100 kg ha^{-1}, the recommended rate for seeding small grains for forage production in central Texas (Redmon, 2011).

Table 27. Adjusted PreN rates at College Station and McGregor, TX in 2011 and 2012.

Location†	Year	PreN Treatments				
		kg ha^{-1}				
		0	45	67	90	112
		Adjusted PreN Treatments ‡ kg ha^{-1}				
ASTREC						
	2012	0	22	45	67	90
Brazos Bottom						
	2011	0	0	11	33	56
	2012	0	0	0	22	45
McGregor						
	2012	0	11	33	56	78

† ASTREC, Animal Science, Teaching, Research, and Extension Complex.

‡ Adjusted for residual NO_3^- present in the uper 15 cm of the soil profile prior to planting.

Plot maintenance occurred on an as-needed basis and employed both mechanical and chemical pest control procedures. Herbicides used include 2, 4-D (0.5 L ha^{-1}), Finesse® Grass and Broadleaf herbicide (52 g ha^{-1}, chlorosulfuron and flucarbozone sodium), and Huskie® (1.1 L ha^{-1}, pyrasulfotol, bromoxynil octanoate, and bromoxynil heptanoate) were used to control any weed infestations present. To reduce yield losses due to insect pressure, applications of Dimethoate (0.25 L ha^{-1}) were made. Insect infestations including Greenbug (*Schizaphis graminum*), bird cherry-oat aphid (*Rhopalosiphum padi*), and army worm (*Pseudaletia unipuncta*) were observed and controlled.

Quantification Methodology

Forage yield and nutritive value were determined by three to four cuttings throughout the season, which occurred when sufficient above ground biomass accumulated (>1,345 kg ha^{-1}). Several measurements were taken on each plot prior to harvest including average plot height, biomass yield rating, Normalized Difference Vegetative Index (NDVI) as determined by near infrared reflectance measurements, percent ground cover determined through analysis of a digital photograph taken 1.5 m above each plot using Assess 2.0 image analysis software (APS Press, St. Paul, MN) and yield determination through clipping three 30.5 cm lengths of row from the interior of the plot. These methods and the data obtained will be discussed in chapter five. Plots were harvested with a Loftness flail type forage harvester equipped with a R-Tech Alfalfa-Omega weigh platform (R-Tech Industries Ltd, MB, Canada). Clipping height averaged 1.5 – 2.5 cm. Total plot weights were taken immediately following harvest and subsamples were taken and weighed in the field. These samples were then dried at 65° C for a minimum of 48 hours to ensure they were devoid of moisture. Once removed from the oven, they were allowed to return to room temperature and weighed again to obtain a dry sample weight. The wet and dry sample weights were then used to determine the total dry matter biomass for each plot by extrapolating moisture percentage in the sample to that of the entire plot.

After the drying and weighing processes were complete, samples were ground to pass through a 1 mm screen, in preparation for nutritive value testing. Nutritive values were determined using a Unity Scientific SpectraStar™ 2500 near infrared spectrophotometer (Foss, Hillerod, Denmark). To initiate the calibration procedure chemical methods were used to determine the chemical composition of a sub set of 65 diverse samples from the studies discussed in this thesis. Constituents measured include crude protein (CP) determined through high temperature combustion, acid detergent fiber (ADF), neutral detergent fiber (NDF), and acid detergent lignin (ADL) determined gravimetrically after liquid digestion, in vitro dry matter digestibility (IVDMD) determined after digestion in harvested rumen fluid, and P, K, Ca, and Mg determined through ICP analysis of nitric acid digest (Texas A&M AgriLife Extension Service, 2012a). These values were then used to parallel NIR derived values, generating a starting calibration equation. After this point, any samples that generated statistical outliers were chemically tested and added to the calibration equation. Additional information on the use of NIR calibration for the prediction of forage nutritive value can be found in Roberts, et al. (2003).

Statistical Analysis

Statistical analysis was conducted with SAS version 9.3 (SAS Institute Inc. Cary, NC) (SAS Institute Inc., 2011) using the general linear model to perform analysis of variance and Duncan's MRT to determine mean separations. Homoscedasticity was tested using Bartlett's test for homogeneity of error variances and correlation was determined through the use of Pearson's product-moment correlation.

Results and Discussion

Seedling Establishment

In wheat stands planted for forage utilization, early establishment and high plant populations are key to increasing early season dry matter production, as opposed to stands intended for grain production. Seedling establishment data is based on counts at the Brazos Bottom in 2011 and from ASTREC and the Brazos Bottom in 2012. Stands varied between environments, with the highest populations attained at ASTREC (44.3 plants m^{-1}) and lowest at the Brazos Bottom (2011, 30.3 plants m^{-1}; 2012, 38.3 plants m^{-1}). Sandy soils less prone to crusting probably set ASTREC apart (Hanks and Thorp, 1956). Little statistical difference in stand establishment was seen in relation to PreN application across all locations. The 0 kg ha^{-1} PreN treatment yielded significantly higher stands than did the 90 kg ha^{-1} PreN treatment, but a significant environment effect suggested different responses to fertilizer application between environments. Individual analysis showed that at the Brazos Bottom in 2011, PreN treatments of 67, 90, and 112 kg ha^{-1} significantly reduced seedling establishment as compared to 0 and 45 kg ha^{-1} treatments. It should be noted that at the Brazos Bottom in 2011, the 0 and 45 kg ha^{-1} treatments both received no N fertilizer, as PreN rates were adjusted for soil N levels shown in Table 27. This trend was not observed at this location in the second year, suggesting another factor such as soil moisture may have acted with fertilizer N in reducing seedling establishment. Increased osmotic potential and ammonia in the germination zone of soils with low levels of available soil moisture could explain this affect (Carter, 1967).

Forage Yield

The response of forage yield to PreN and PostN treatments was highly variable within and across locations. Highly significant treatment by environment interactions were observed, thus data was not combined across environments. Planting and forage harvest dates for each study location can be found in Table 28, along with mean forage yield for each cutting.

Brazos Bottom

Several trends in forage yield were observed in relation to nitrogen application. Data from the first cutting at the Brazos Bottom in 2011 (Fig. 3) shows a reduction in dry matter yield in all treatments where N was applied prior to planting. Reductions in forage yield ranged from 170 – 275 kg ha^{-1}. The largest reduction in yield resulted from the 112 kg ha^{-1} PreN treatment that consisted of 56 kg ha^{-1} applied N, which produced significantly less dry matter in the first cutting as compared to the 0 and 45 kg ha^{-1} treatments receiving no fertilizer N. This yield data might be questionable due to a CV for this cutting of 56%, but when taken into consideration along with stand establishment and precipitation data, the data suggests that the yield loss that resulted in treatments receiving pre-plant N can probably be attributed to reduced seedling establishment and persistent drought conditions. Without adequate soil moisture, wheat plants could not utilize added N to compensate for low populations through increased tissue growth and tillering.

Forage yield from the second harvest show less differentiation in forage yield in relation to PreN treatment as compared to the first cutting (Fig. 4). With precipitation events totaling 9.5 cm prior to the second harvest, yield for treatments that received pre-plant N were much higher in relation to the untreated checks, as compared to the first cutting. With adequate moisture, PreN treatments did increase dry matter production, when stand establishment was taken into account. Figure 4 also illustrates the variability experienced in this study. There was a difference of approximately 130 kg ha^{-1} between the 0 and 45 kg ha^{-1} PreN treatments, which both received no pre-plant N. This variability may explain why the 45 kg ha^{-1} PreN treatment produced significantly more dry matter than the 67 kg ha^{-1} PreN treatment.

Similar conclusions can be drawn from data for the third and fourth cuttings (Fig. 5 and 6, respectively). In the third forage harvest, the 67 kg ha^{-1} treatment yielded significantly more dry matter than did the 45 kg ha^{-1} treatment, which is a reversal from the previous cutting. Treatments receiving pre-plant N also increased forage yield in relation to checks. In the fourth cutting, the relationship between dry matter production and pre-plant N corresponds with the expected results, where dry matter yield increased with increasing PreN rate, then decrease with the highest PreN rate (Fig. 6). However, no statistically significant difference in forage yield was observed between any treatments in the fourth cutting.

Table 28. Planting and harvest dates with mean forage yield at College Station and McGregor, TX in 2011 and 2012.

Year	Location†	Planting Date	Forage Harvest Date(s)	Forage Yield Mean	CV, %
2011				kg ha^{-1}	
	Brazos Bottom	9/21/10	12/16/10	541	56
			2/8/11	992	28
			3/1/11	846	15
			3/24/11	355	38
2012					
	ASTREC	9/23/11	2/6/12	3,274	17
			3/23/12	3,476	18
	Brazos Bottom	9/22/11	12/1/11	2,408	17
			1/19/12	1,738	20
			2/29/12	3,188	14
	McGregor	9/30/11	1/6/12	2,537	35
			2/27/12	2,337	23
			4/5/12	2,809	13

† ASTREC, Animal Science, Teaching, Research, and Extension Complex.

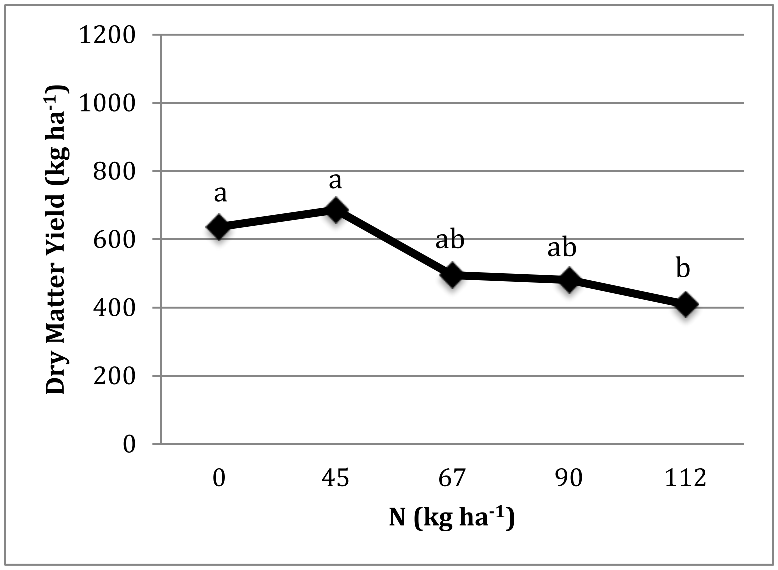

Fig. 3. Mean dry matter yield at the first cutting (12/16/10) based on pre-plant N at the Brazos Bottom, College Station, TX 2011. Treatments with the same letters are not statistically different according to Duncan's MRT.

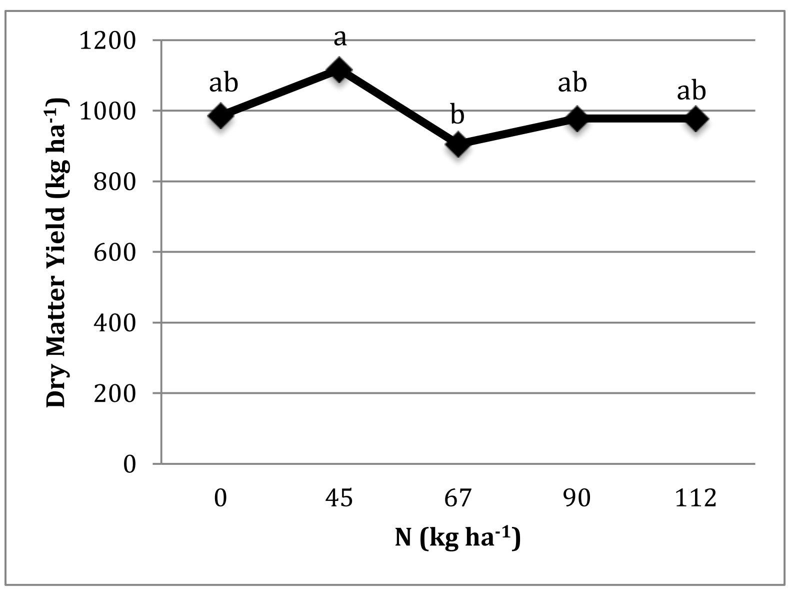

Fig. 4. Mean dry matter yield at the second cutting (2/8/11) based on pre-plant N at the Brazos Bottom, College Station, TX in 2011. Treatments with the same letters are not statistically different according to Duncan's MRT.

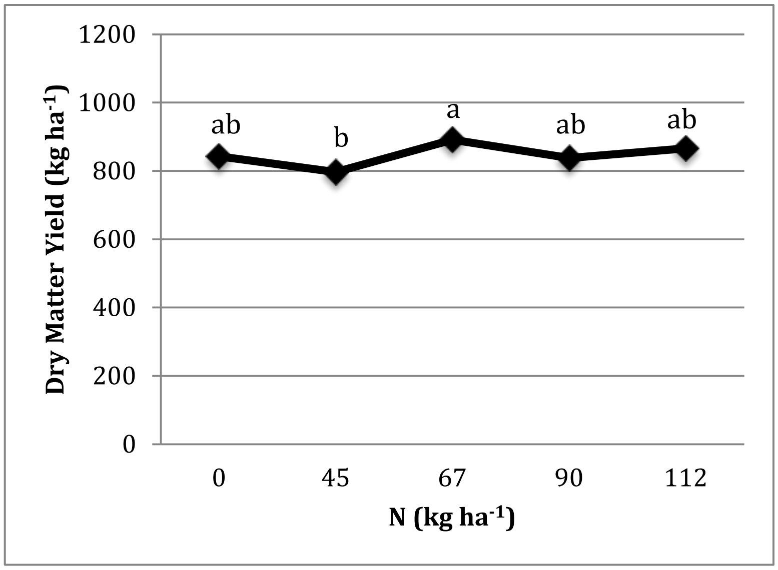

Fig. 5. Mean dry matter yield at the third cutting (3/1/11) based on pre-plant N at the Brazos Bottom, College Station, TX in 2011. Treatments with the same letters are not statistically different according to Duncan's MRT.

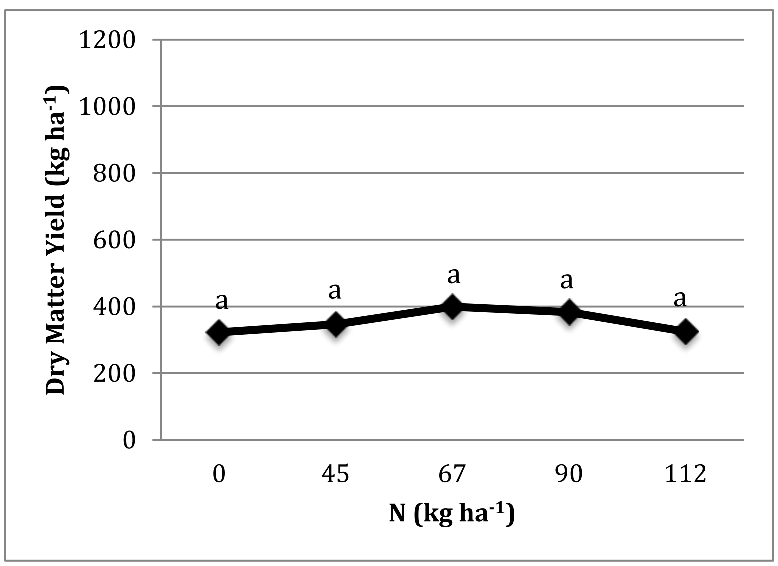

Fig. 6. Mean dry matter yield at the fourth cutting (3/24/11) based on pre-plant N at the Brazos Bottom, College Station, TX in 2011. Treatments with the same letters are not statistically different according to Duncan's MRT.

In terms of total forage production after four cuttings, results are very similar to that of the first forage harvest (Fig. 3 and 7). The two PreN treatments that served as untreated checks produced more dry matter over the four forage harvests than did any that received pre-plant N (Fig. 7). Statistically, the 45 kg ha^{-1} PreN treatment produced significantly more forage during the season than did the 112 kg ha^{-1} treatment. All other treatment comparisons showed no statistical significance. This suggests that, although PreN treatments were able to compensate for reduced stands over time, early season forage production is an important part of total annual forage production in extremely dry environments such as that experienced at the Brazos Bottom in the 2011 season.

At the Brazos Bottom in 2011, PostN treatments had little effect on forage production in any single cutting. Statistically speaking, there were no significant differences in dry matter production between PostN treatments in the second, third, or fourth cuttings. Forage yield did tend to increase as top-dress N increased in all but the fourth cutting, but these trends were significantly different. Mean forage yield ranges for each cutting were generally only 50 – 100 kg ha^{-1}, with the exception of the second cutting where the range was 180 kg ha^{-1}. Precipitation events prior to this cutting are probably responsible for greater differentiation by enabling higher growth rates and increased N uptake. When analyzed by total forage yield for all four cuttings, the 67 kg ha^{-1} PostN treatment produced significantly more biomass than the 45 kg ha^{-1} PostN treatment (Fig. 8). PostN treatment means somewhat follow the expected forage yield response to added N fertilizer, but with a slight loss of yield with increasing fertilizer

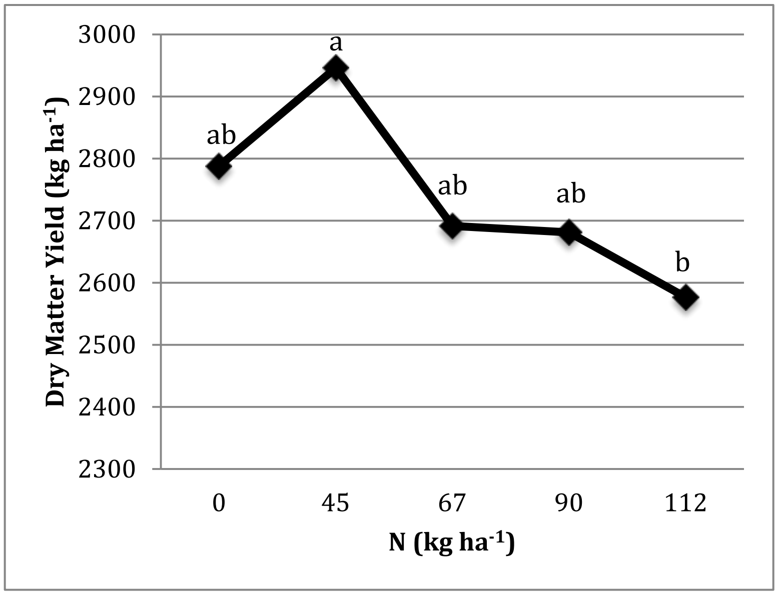

Fig. 7. Mean total forage yield based on pre-plant N at the Brazos Bottom, College Station, TX in 2011. Treatments with the same letters are not statistically different according to Duncan's MRT.

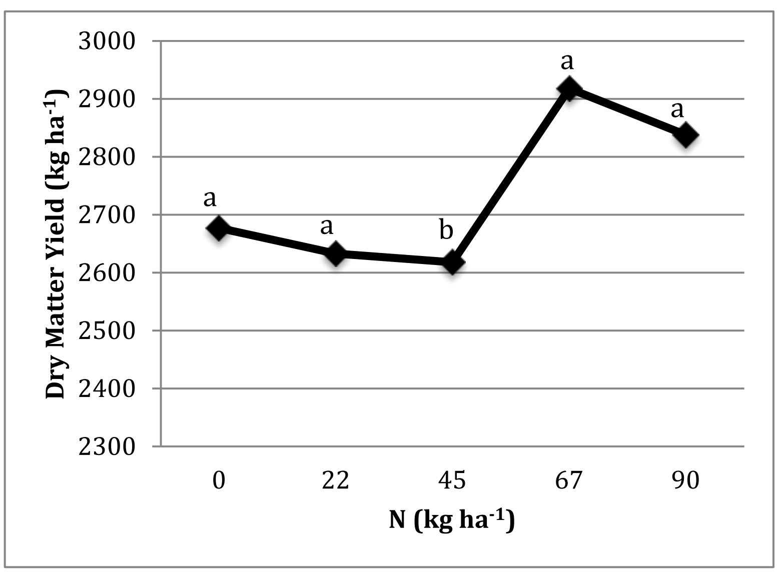

Fig. 8. Mean total forage yield based on top-dress N at the Brazos Bottom, College Station, TX in 2011. Treatments with the same letters are not statistically different according to Duncan's MRT.

rate up to 45 kg ha^{-1}, then a drastic increase with the 67 kg ha^{-1} PostN rate and a slight decrease with the 90 kg ha^{-1} PostN treatment (Fig. 8).

Precipitation and total dry matter yield in the second year at the Brazos Bottom were more than double that of the previous season. During the 2012 season, forage yield was highly variable in relation to PreN treatments. PreN rates were adjusted to accommodate 67 kg ha^{-1} residual soil N, therefore reducing the ability of this test to detect differences in forage production due to pre-plant N application. No significant differences in forage production were observed in relation to PreN treatment in any single cutting. There was a significant difference in season total forage production between the 0 and 45 kg ha^{-1} PreN treatments, but these treatments both received no pre-plant N. These findings show the high level of variability seen in this experiment (Fig. 9).

Despite the variability and lack of yield response to PreN treatments, PostN treatments produced results that were similar to the expected results (Fig.10). In the second cutting, there were no significant differences in forage yield, but yield did increase with increasing PostN rate. The 45 kg ha^{-1} rate produced the largest increase in dry matter production (Fig. 10). Dry matter yield for the third cutting (Fig. 11) showed a similar response to PostN treatments. Statistically, the 90 kg ha^{-1} treatment out yielded the untreated check and the 22 kg ha^{-1} treatment, and the 45 and 67 kg ha^{-1} treatments out yielded the untreated check.

Overall, the 45 kg ha^{-1} PostN treatment produced the greatest increase in total forage yield at the Brazos Bottom in 2012. The trend line of the season total forage yield means (Fig. 12) show the greatest increase in forage yield over the untreated check with the 45 kg ha^{-1} PostN treatment. Statistically, the 45 kg ha^{-1} treatment out yielded the untreated check and the 22 kg ha^{-1} treatments, and the 67 and 90 kg ha^{-1} out yielded the untreated check.

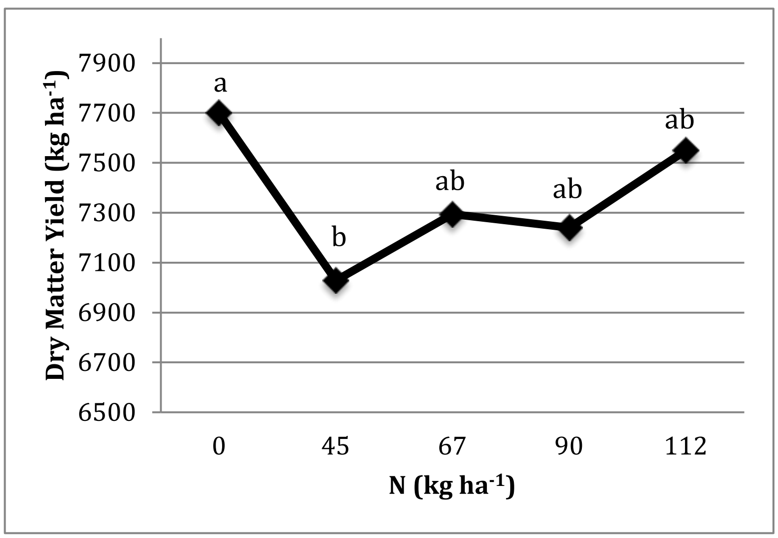

Fig. 9. Mean total forage yield based on pre-plant N at the Brazos Bottom, College Station, TX in 2012. Treatments with the same letters are not statistically different according to Duncan's MRT.

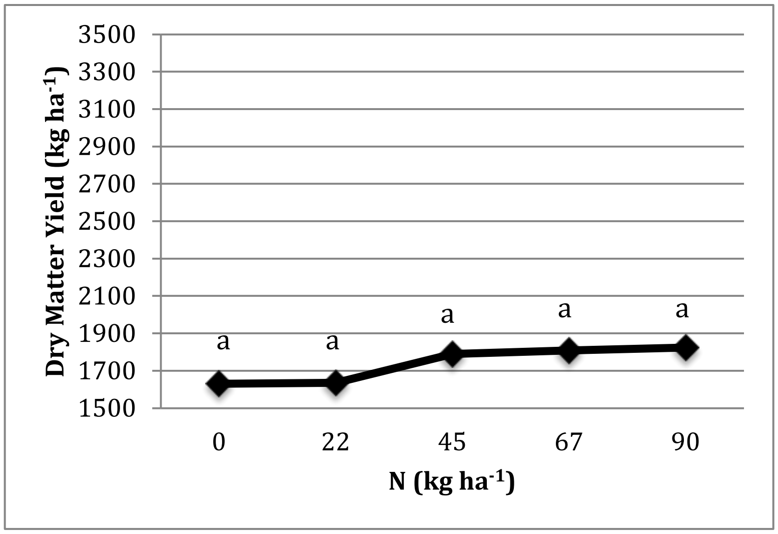

Fig. 10. Mean dry matter yield at the second cutting (1/19/12) based on top-dress N at the Brazos Bottom, College Station, TX in 2012. Treatments with the same letters are not statistically different according to Duncan's MRT.

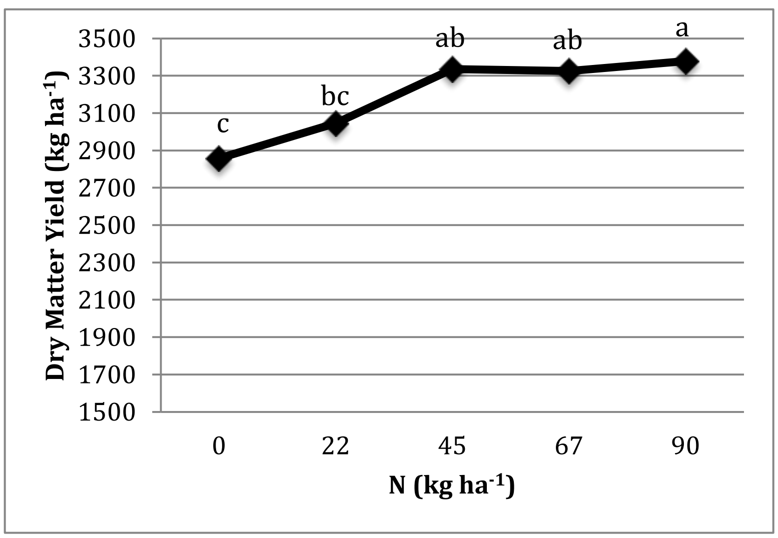

Fig. 11. Mean dry matter yield at the third cutting (2/29/12) based on top-dress N at the Brazos Bottom, College Station, TX in 2012. Treatments with the same letters are not statistically different according to Duncan's MRT.

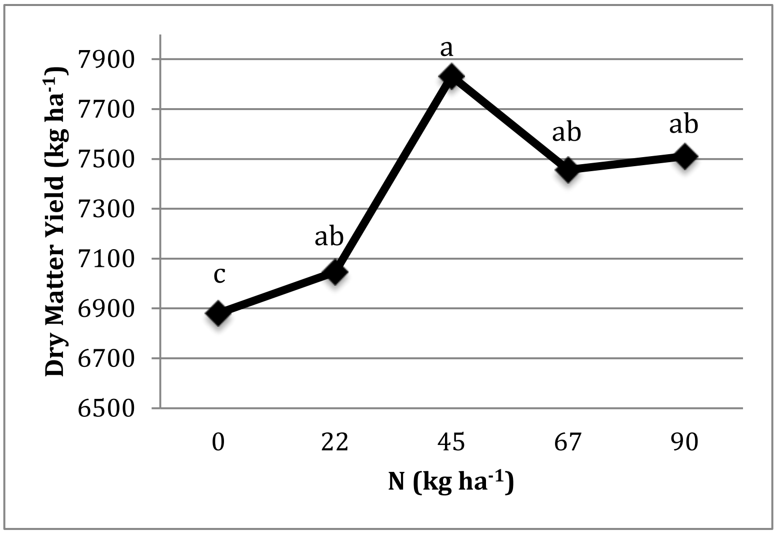

Fig. 12. Mean total forage yield based on top-dress N at the Brazos Bottom, College Station, TX in 2012. Treatments with the same letters are not statistically different according to Duncan's MRT.

ASTREC

Overall, results at ASTREC closely followed the expected trends for this study. This may be due to the low level of residual N present in the upper 15 cm of the soil profile, allowing fertilizer N to produce more distinct results. Fig. 13 and 14 below depict the relationship of added N affect on season total forage yield. Pre-plant fertilizer increased season total yield incrementally to a threshold of around 7125 kg ha^{-1} dry matter when 90 kg ha^{-1} N was added, where after additional N caused a decline in dry matter yield (Fig. 13). A similar trend can be seen with PostN (Fig. 14) where forage yield increases with increasing N to a level of 45 kg ha^{-1}, at which point additional N did not increase forage yield. Statistically, the PreN rate of 90 kg ha^{-1} out yielded the untreated check. The PostN rates of 45, 67, and 90 kg ha^{-1} out yielded the untreated check and the 22 kg ha^{-1} treatment. When analyzed by cutting, the PreN rate of 90 kg ha^{-1} produced more dry matter per acre than did any other treatment, including the untreated check in the first cutting. In the second cutting, PreN rate did not have a significant affect on forage yield. PostN treatments did, however, show an effect on dry matter yield, with the PostN treatment of 67 kg ha^{-1} out performing the 22 kg ha^{-1} and the untreated check. The 45 and 90 kg ha^{-1} also out yielded the untreated check.

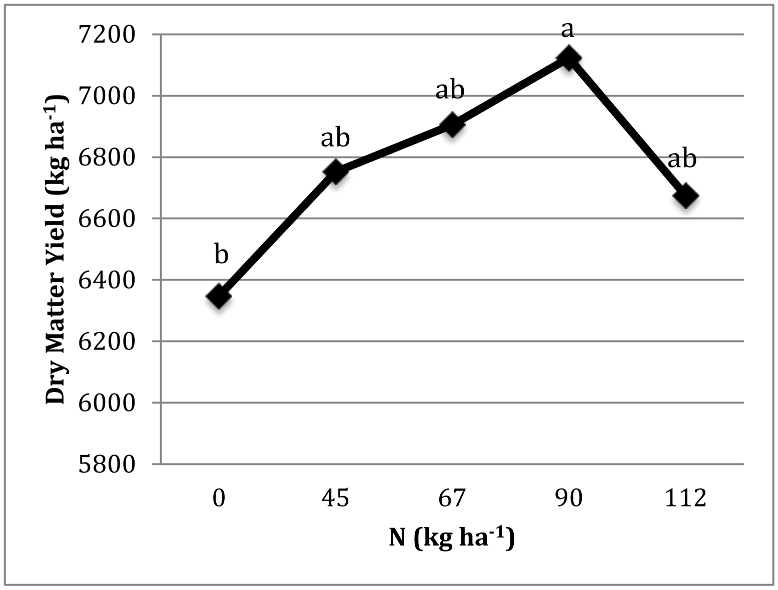

Fig. 13. Mean total forage yield based on pre-plant N at the Animal Science, Teaching, Research, and Extension Center (ASTREC), College Station, TX in 2012. Treatments with the same letters are not statistically different according to Duncan's MRT.

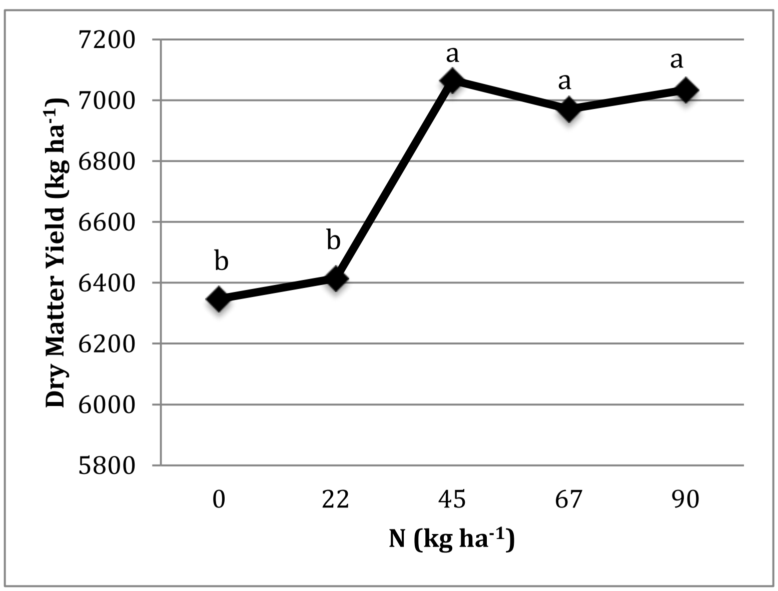

Fig. 14. Mean total forage yield based on top-dress N at the Animal Science, Teaching, Research, and Extension Center (ASTREC), College Station, TX in 2012. Treatments with the same letters are not statistically different according to Duncan's MRT.

McGregor

At McGregor in 2012, the relationship between forage yield and applied N was somewhat sporadic. This result was unexpected, as residual soil N levels were low, with soil test N only showing 14 ppm nitrate-N in the upper 15 cm of soil. Above average rainfall may have influenced applied N placement through runoff and leaching events, as all treatments were applied to the soil surface. Organic matter mineralization of N might have also played a role in these unexpected results, increasing the amount of N available in the soil.

In the first cutting at McGregor in 2012, the 67 kg ha^{-1} PreN treatment yielded significantly more dry matter than the 45, 90, and 112 kg ha^{-1} treatments. High variability was observed, with a CV of 35. The same statistical results were seen in total forage production (Fig. 15). This type of relationship between early season forage yield and year total forage yield was also observed at the Brazos Bottom in 2011, backing up the idea that early season forage production is a very important part of season long productivity of wheat stands.

The second forage harvest produced results much different from any other observed. Forage yield showed a negative relationship with both PreN and PostN treatments. Statistically speaking, the significant differences observed were with PostN treatments, where the untreated check out yielded the 90 kg ha^{-1} PostN treatment. With above average rainfall experienced throughout the season, rapid growth and N uptake would be expected. Tissue damage from top-dress application of urea ammonium nitrate immediately following clipping could be the cause of this particular trend, if stunting resulted and slowed the initial recovery from clipping. No data was collected on post application tissue damage, thus more data is needed to make any conclusions relating to this hypothesis.

Results from the third cutting at this location showed no significant difference between any treatments and no noticeable trends (Table 28). This cutting occurred very late in the season, by which point maximum potential forage production for wheat in that environment may have been met. More differentiation between treatments may have been seen if this final harvest were completed prior to heading.

Season total forage yield data from McGregor in 2012 showed that the 67 kg ha^{-1} treatment out yielded all PreN treatments but the untreated check. Season total forage yield with respect to PostN treatments showed less differentiation, but followed the expected trend with the exception of relatively low yield for the 45 kg ha^{-1} PostN treatment (Fig. 16).

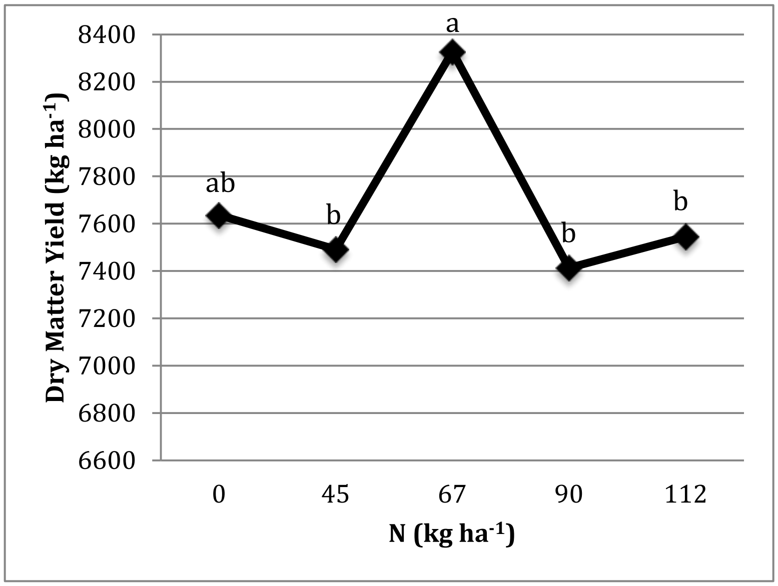

Fig. 15. Mean total forage yield based on pre-plant N at McGregot, TX in 2012. Treatments with the same letters are not statistically different according to Duncan's MRT.

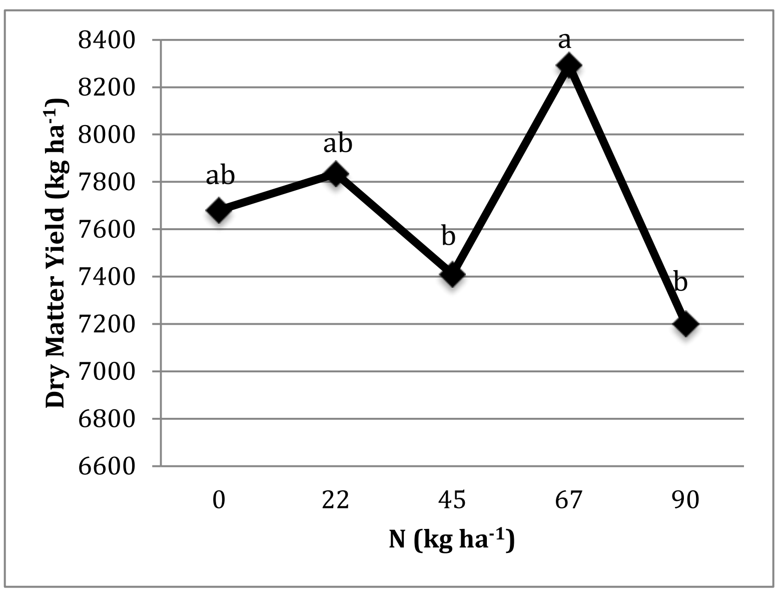

Fig. 16. Mean total forage yield based on post-plant N at McGregor, TX in 2012. Treatments with the same letters are not statistically different according to Duncan's MRT.

Forage Nutritive Value

Forage nutritive value data was taken from all cuttings at all locations in this study. In this section, nutritive value data points from each sampling were averaged by location to yield a value that represents the average nutritive value over the season. In this manner we combined several data points into one providing a means to better describe the nutritional status of the forage over the entire growing season. Analysis of variation for nutritive value data showed that there were interactions between environments and treatments for each descriptor of nutritive value, thus data is discussed by environment.

Crude Protein

As expected, CP content of forages was positively related to amount of fertilizer N applied in both PreN and PostN treatments, with the exception of pre-plant treatments at the Brazos Bottom in 2012 where no significant differences due to PreN treatment were seen. This environment exhibited the highest level of residual soil N of any location used, thus adjustments to PreN treatments reduced differences in pre-plant N between treatments. Forage CP means did increase with increasing PostN rate, but only the 90 kg ha^{-1} rate was significantly different from the untreated check (Fig. 17). At ASTREC, both PreN and PostN treatments produced significant increases in CP content (Fig. 18 and 19, respectively). Less differentiation between PostN treatments in this environment as compared to others and much lower CP contents can be attributed to fewer top-dress N applications and sandy soils very prone to leaching due to soil water movement and low cation exchange capacity.

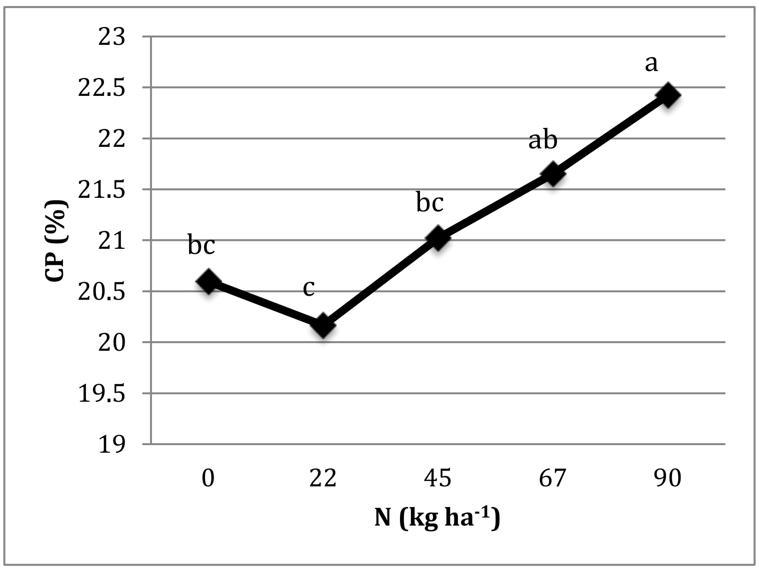

Fig. 17. Mean season average crude protein content based on post-plant N at the Brazos Bottom, College Station, TX in 2012. Treatments with the same letters are not statistically different according to Duncan's MRT.

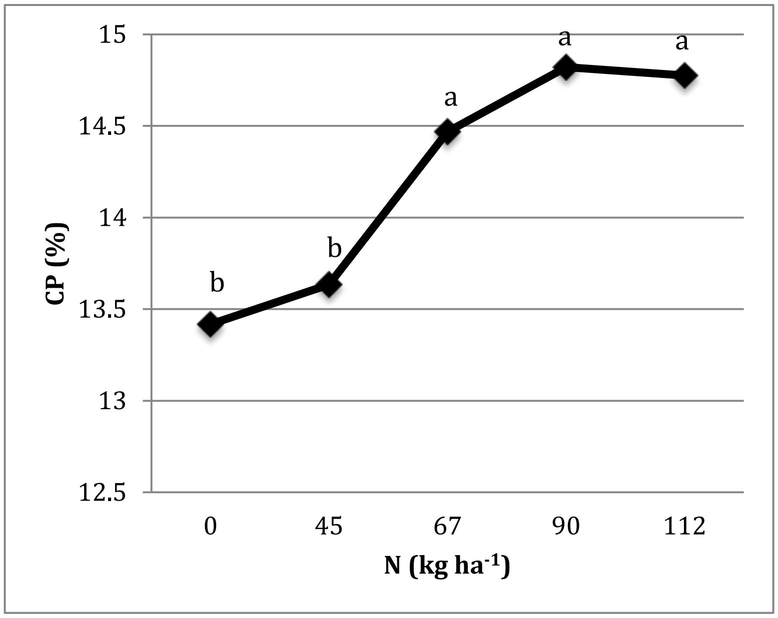

Fig. 18. Mean season average crude protein content based on pre-plant N at the Animal Science, Teaching, Research, and Extension Center (ASTREC), College Station, TX in 2012. Treatments with the same letters are not statistically different according to Duncan's MRT.

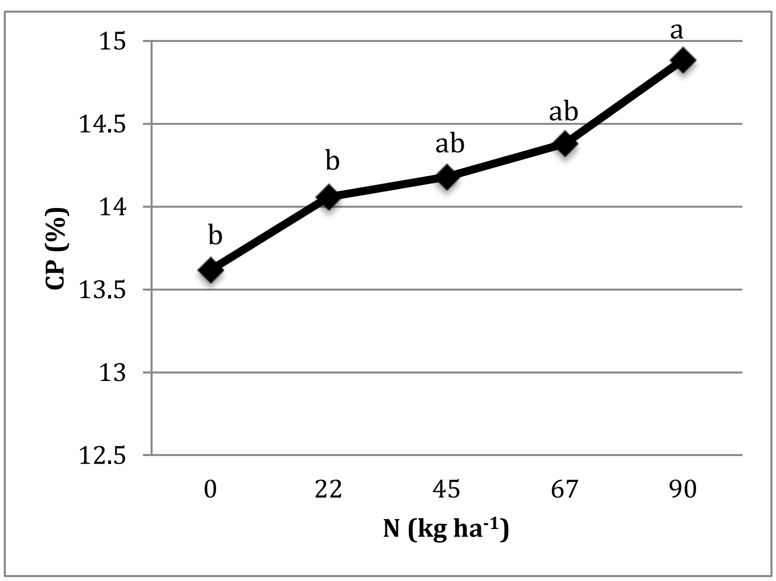

Fig. 19. Mean season average crude protein content based on top-dress N at the Animal Science, Teaching, Research, and Extension Center (ASTREC), College Station, TX in 2012. Treatments with the same letters are not statistically different according to Duncan's MRT.

Results from the Brazos Bottom in 2011 follow expected results with CP increasing as applied N increased. Figure 20 depicts the linear increase in CP content as PreN rate was increased and Fig. 21 shows the increase in CP at a decreasing rate as PostN rate increased. This agrees with the findings of Mitchell, et al. (2000).

The greatest increase in forage CP content due to N treatment was seen at McGregor. At all other locations, the range in treatment mean CP content was generally around 2 percentage points. In this environment, the range in CP means for PostN treatments was slightly greater than 4 percentage points. CP content means did follow the expected trend, where CP increased as applied N increased for both PreN and PostN treatments, and are graphically represented in (Fig. 22 and 23, respectively).

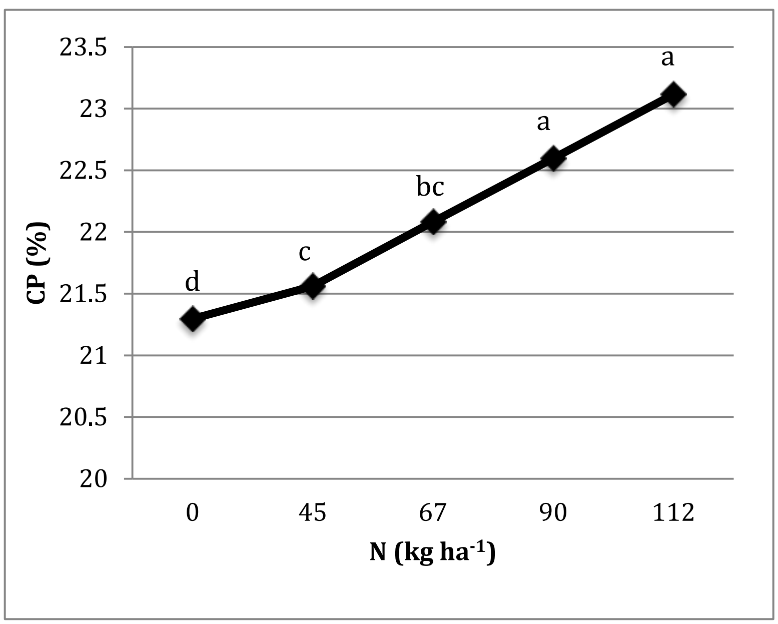

Fig. 20. Mean season average crude protein content based on pre-plant N at the Brazos Bottom, College Station, TX in 2011. Treatments with the same letters are not statistically different according to Duncan's MRT.

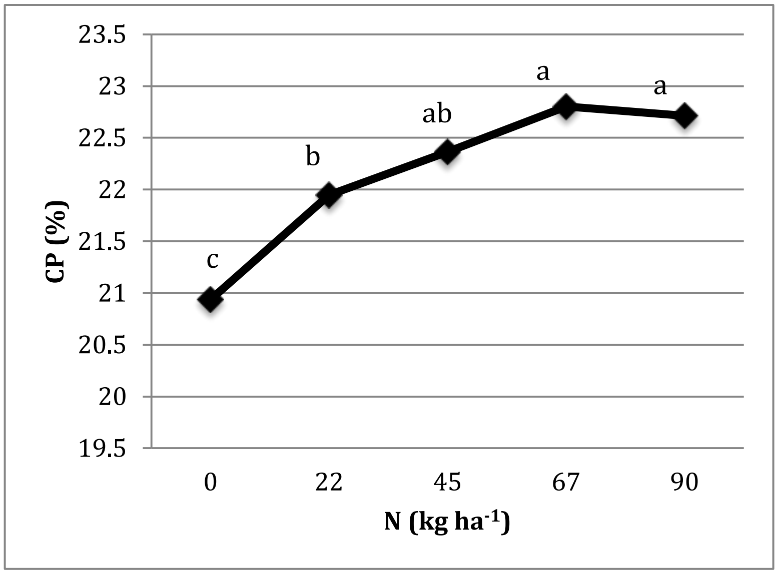

Fig. 21. Mean season average crude protein content based on top-dress N at the Brazos Bottom, College Station, TX in 2011. Treatments with the same letters are not statistically different according to Duncan's MRT.

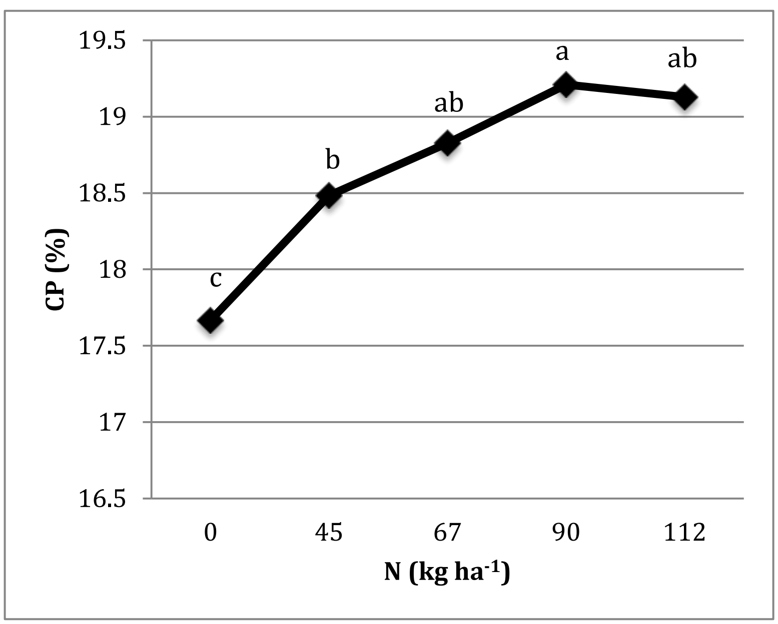

Fig. 22. Mean season average crude protein content based on pre-plant N at McGregor, TX in 2012. Treatments with the same letters are not statistically different according to Duncan's MRT.

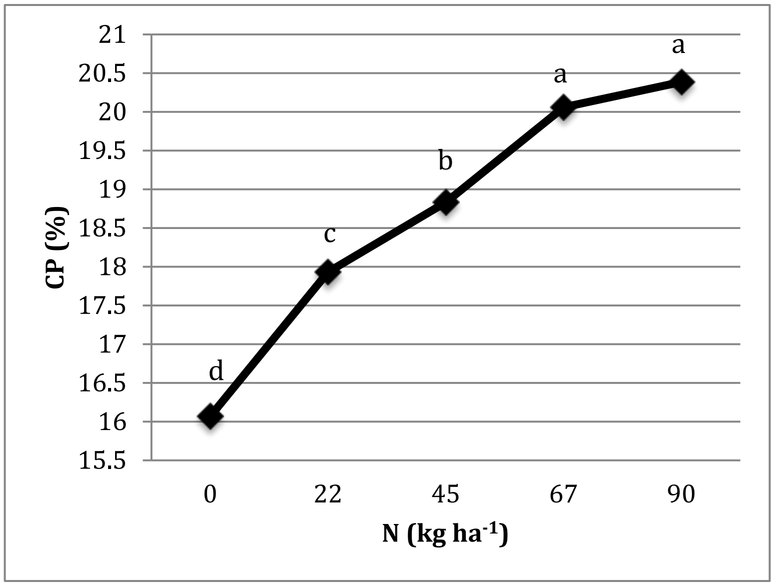

Fig. 23. Mean season average crude protein content based on top-dress N at Mc Gregor, TX in 2012. Treatments with the same letters are not statistically different according to Duncan's MRT.

Total Digestible Nutrients

Over all, TDN values tended to increase with increasing pre-plant and top-dress N rate; however, the range in TDN between treatments at a single location did not exceed 2 percentage points. At the Brazos Bottom in 2011, significant differences in TDN were observed in relation to PreN treatments where TDN increased as PreN rate increased (Fig. 24). PostN treatments created a similar trend in mean TDN value (Fig. 25), where all PostN treatments produced forages with significantly higher TDN values than the untreated check. At McGregor in 2012, forage from the 90 kg ha^{-1} PreN treatment had a significantly higher mean TDN than the untreated check. For PostN treatments, TDN increased as N rate increased. Graphical representations of means for both PreN and PostN treatments can be seen in Fig. 26 and 27, respectively. TDN means from ASTREC also showed this result with the 90 kg ha^{-1} PreN treatment producing significantly higher forage TDN values than the untreated check and the 45 kg ha^{-1} treatment and the 90 kg ha^{-1} PostN treatment producing significantly higher TDN values than 45 kg ha^{-1} treatment.

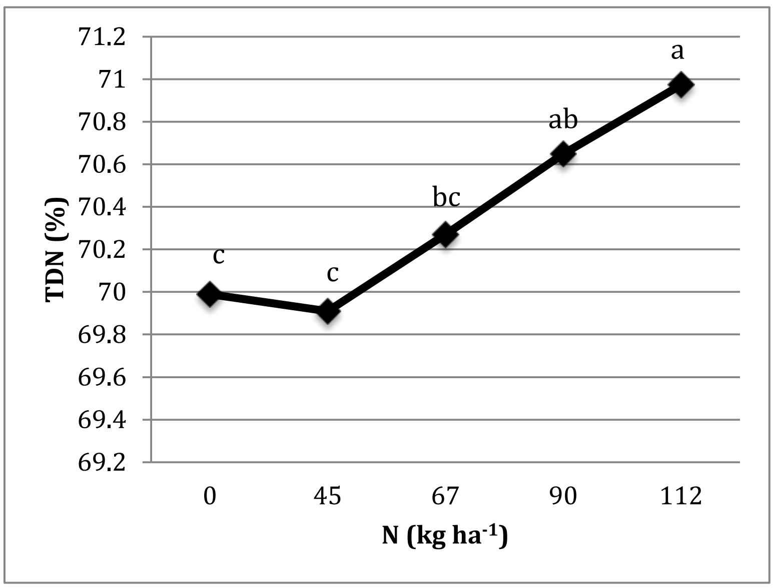

Fig. 24. Mean season average total digestible nutrient content based on pre-plant N at the Brazos Bottom, College Station, TX in 2011. Treatments with the same letters are not statistically different according to Duncan's MRT.

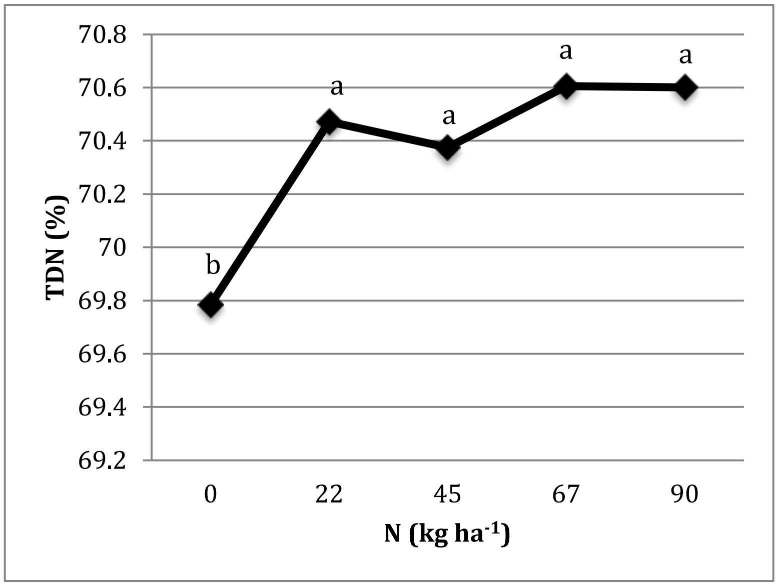

Fig. 25. Mean season average total digestible nutrient content based on top-dress N at the Brazos Bottom, College Station, TX in 2011. Treatments with the same letters are not statistically different according to Duncan's MRT.

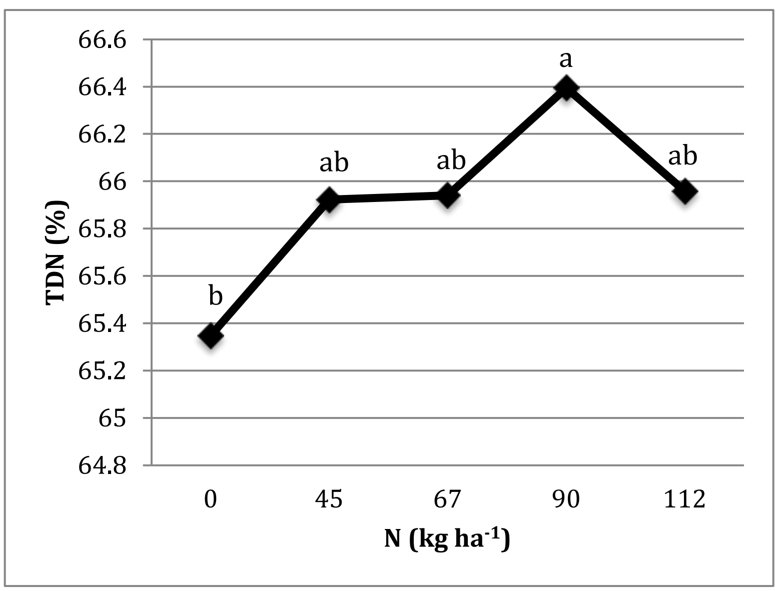

Fig. 26. Mean season average total digestible nutrient content content based on pre-plant N at McGregor, TX in 2012. Treatments with the same letters are not statistically different according to Duncan's MRT.

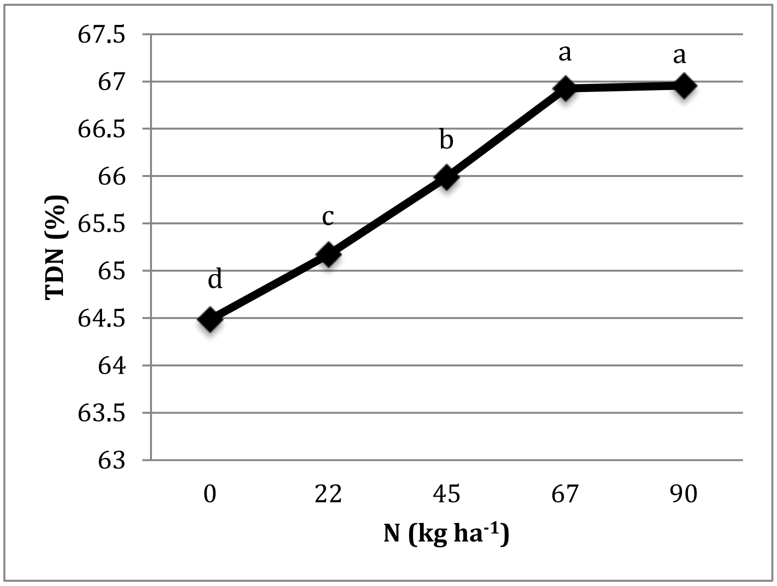

Fig. 27. Mean season average total digestible nutrient content based on top-dress N at McGregor, TX in 2012. Treatments with the same letters are not statistically different according to Duncan's MRT.

TDN values from the Brazos Bottom in 2012 deviated from the trends observed at the locations previously described. In this environment, the untreated check yielded significantly higher TDN values than the 45 kg ha^{-1} PreN treatment. This result was not expected as this treatment also yielded significantly less dry matter production over the season, but more fertilizer N. Results related to PostN treatments yielded no significant differences in TDN, but values did follow an increasing trend (Fig. 28).

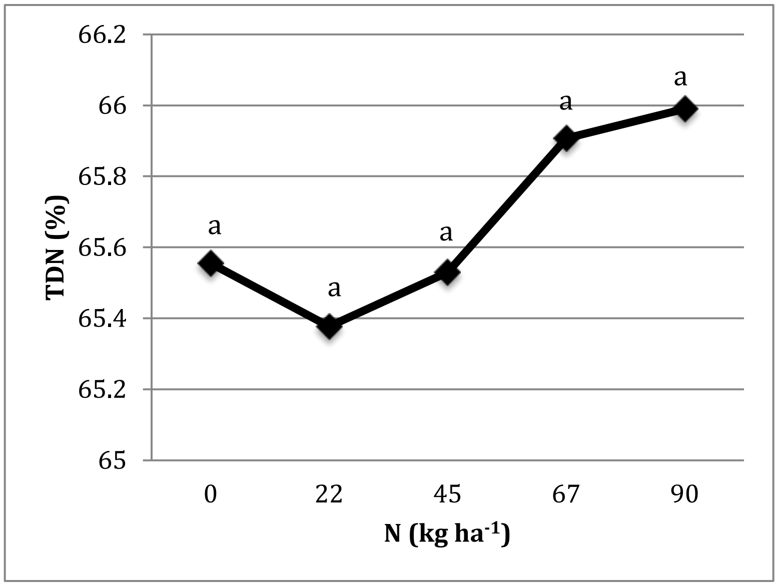

Fig. 28. Mean season average total digestible nutrient content based on top-dress N at the Brazos Bottom, College Station, TX in 2012. Treatments with the same letters are not statistically different according to Duncan's MRT.

Phosphorous

Forage P concentrations also increased with increasing N application overall. This contradicts the findings of Mitchell, et al. (2000) who found that N fertilization had no effect on tissue P concentration. PreN treatments had little significant effect on forage P concentrations, but significant differences were seen at McGregor and the Brazos Bottom in 2011. At McGregor, all PreN treatments induced significantly higher forage P than the untreated check, with the exception of the 45 kg ha^{-1} PreN treatment. At the Brazos Bottom in 2011, more statistical separation between treatments was seen (Fig. 29). PreN treatments at all other locations followed similar trends, but there is no statistical evidence to support this.

PostN treatments had a much greater effect on forage P concentrations, with means from each environment showing heightened P levels with the addition of top-dress N fertilizer. At ASTREC and the Brazos Bottom in 2011, PostN rates of 45 kg ha^{-1} and greater significantly increased forage P concentrations versus the untreated check and the 22 kg ha^{-1} treatment. In 2012, more statistical separation between PostN treatment means for P concentration was observed at the Brazos Bottom and McGregor according to Duncan's MRT (Fig. 30 and 31, respectively).

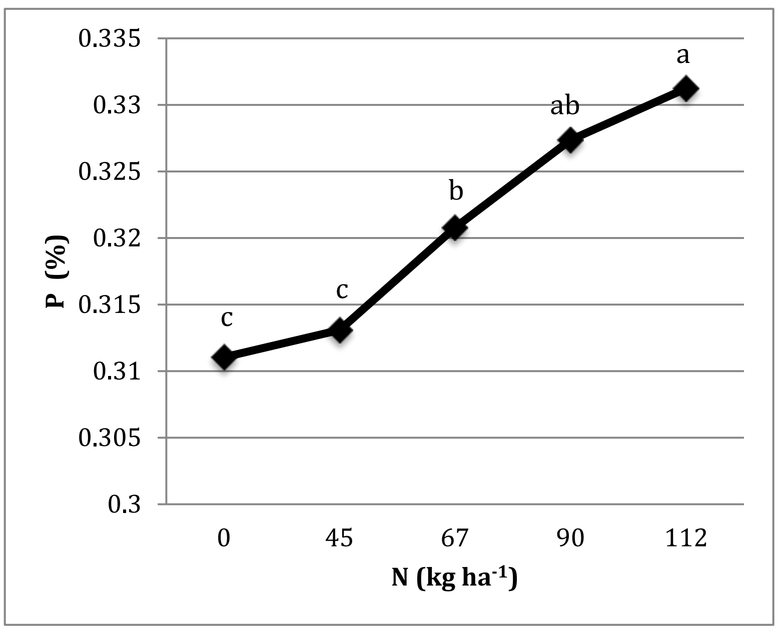

Fig. 29. Mean season average tissue P content based on pre-plant N at the Brazos Bottom, College Station, TX in 2011. Treatments with the same letters are not statistically different according to Duncan's MRT.

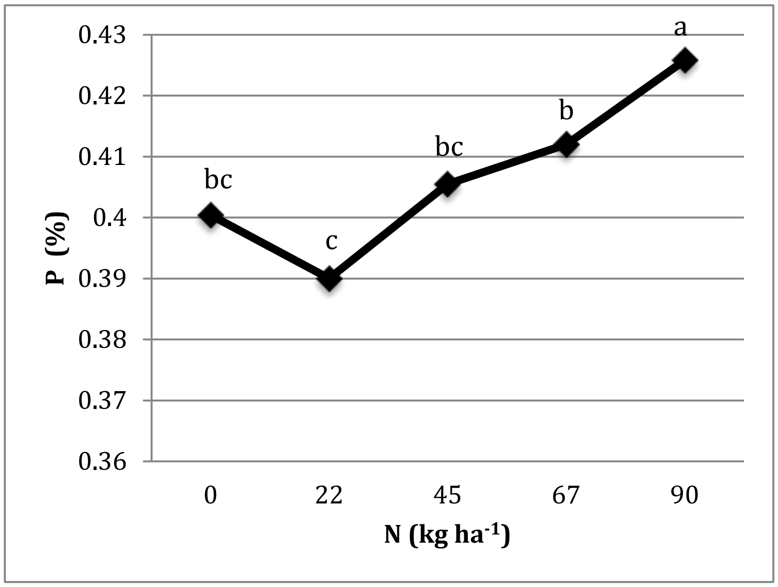

Fig. 30. Mean season average tissue P content based on top-dress N at the Brazos Bottom, College Station, TX in 2012. Treatments with the same letters are not statistically different according to Duncan's MRT.

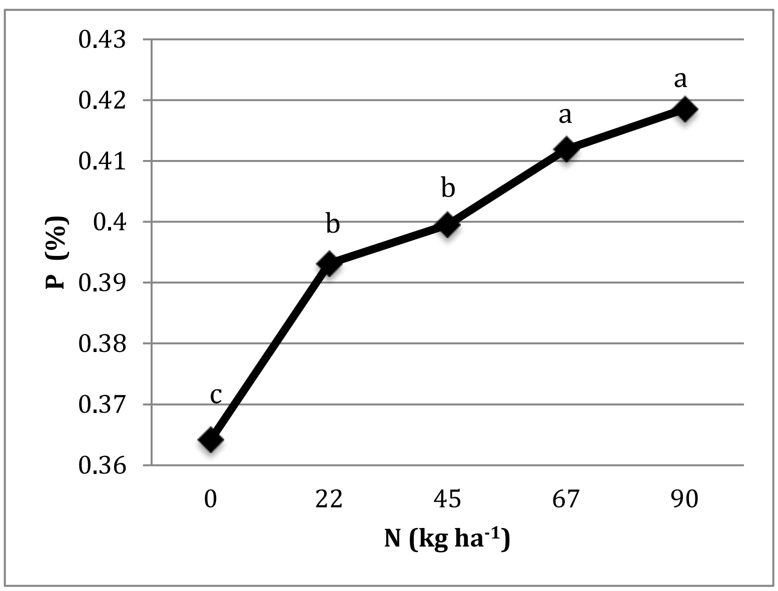

Fig. 31. Mean season average tissue P content based on top-dress N at the McGregor, TX in 2012. Treatments with the same letters are not statistically different according to Duncan's MRT.

Potassium

PreN treatments also had little effect on forage K content. Forage K content means tended to increase with increasing PreN rate, but significant increases were only seen at the Brazos Bottom in 2011. At the Brazos Bottom in 2011, all PreN treatments significantly increased forage K content over the untreated check (Fig. 32). PostN treatments had a much greater effect on forage K contents. In both years at the Brazos Bottom, forage K means for PostN treatments 45 kg ha^{-1} and greater were significantly higher than the untreated check and the 22 kg ha^{-1} PostN treatment. Similarly, forage K means for all PostN treatments were significantly higher than the untreated check at McGregor. Results from ASTREC were atypical in that K concentrations did not increase with increasing N rate. Forage K means from the 90 kg ha^{-1} PostN treatment were significantly higher than the 22 and 67 kg ha^{-1} treatments, but statistically the same as the untreated check and the 45 kg ha^{-1} treatments. Forage K means were well in excess of the requirements for growing steer and heifer calves, and neared or exceeded the maximum tolerable levels for that class of animal at the Brazos Bottom and McGregor according to the National Research Council (1996).

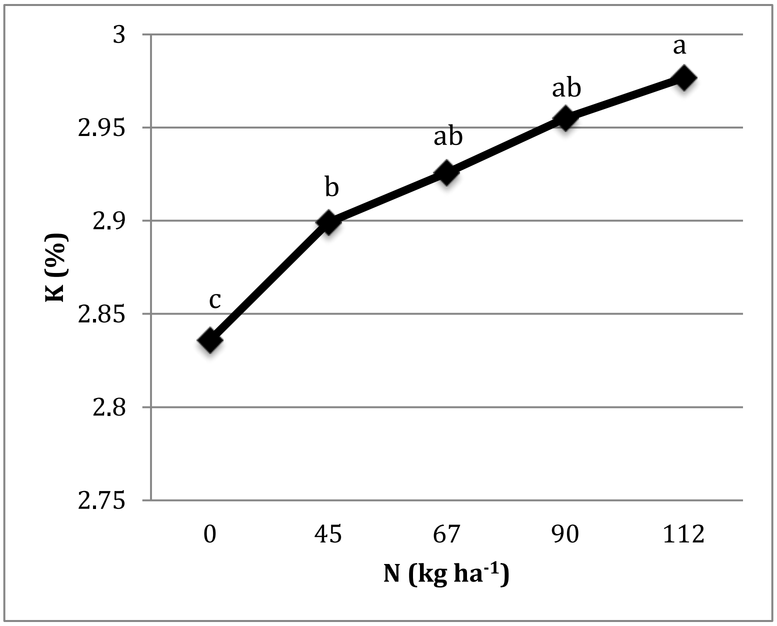

Fig. 32. Mean season average tissue K content based on pre-plant N at the Brazos Bottom, College Station, TX in 2011. Treatments with the same letters are not statistically different according to Duncan's MRT.

Calcium and Magnesium

Forage Ca and Mg contents were not different in any pre- or post-plant treatments at the Brazos Bottom, with the exception of Mg content in 2011, where all PostN treatments contained significantly more Mg than the untreated check. Forage Ca means at the Brazos Bottom in 2012 also showed a significant difference, where forage from the untreated check had significantly higher Ca content than the 67 kg ha^{-1} PostN treatment (Fig. 33). In this case, Ca content also showed a slight negative relationship with PostN fertilizer.

At McGregor and ASTREC, forage Ca and Mg content had a positive relationship with pre- and post-plant N application. At McGregor, average forage Ca content of the 112 kg ha^{-1} PreN treatment and all PostN treatments (Fig. 34 and 35, respectively) were significantly higher than the untreated checks. The 90 kg ha^{-1} PostN treatment also exhibited significantly higher forage Ca content than the 22 kg ha^{-1} treatment. Average forage Mg content was significantly higher in the 90 and 112 kg ha^{-1} PreN treatments than in the untreated check. The 112 kg ha^{-1} PreN treatment also produced significantly higher Mg contents than the 45 and 67 kg ha^{-1} PreN treatments (Fig. 36). All forages from PostN treatments at McGregor had significantly higher Mg contents than the untreated check. The 90 kg ha^{-1} PostN treatment also had significantly higher forage Mg content than the other PostN treatments shown in Fig. 37.

Forage Ca means responded in a similar way at ASTREC. The Ca means for PreN and PostN treatments with means separations are presented in Fig. 38 and 39, respectively. Forage Mg content was significantly higher in the 112 kg ha^{-1} PreN treatment than in the untreated check. Forage Mg content means associated with PreN treatments are presented in Fig. 40. There were no statistically significant differences in forage Mg content in PostN treatments.

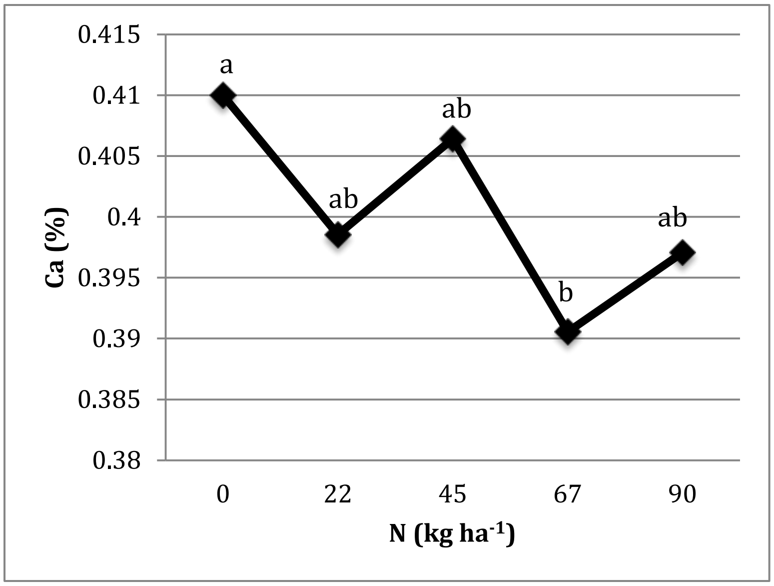

Fig. 33. Mean season average tissue Ca content based on top-dress N at the Brazos Bottom, College Station, TX in 2012. Treatments with the same letters are not statistically different according to Duncan's MRT.

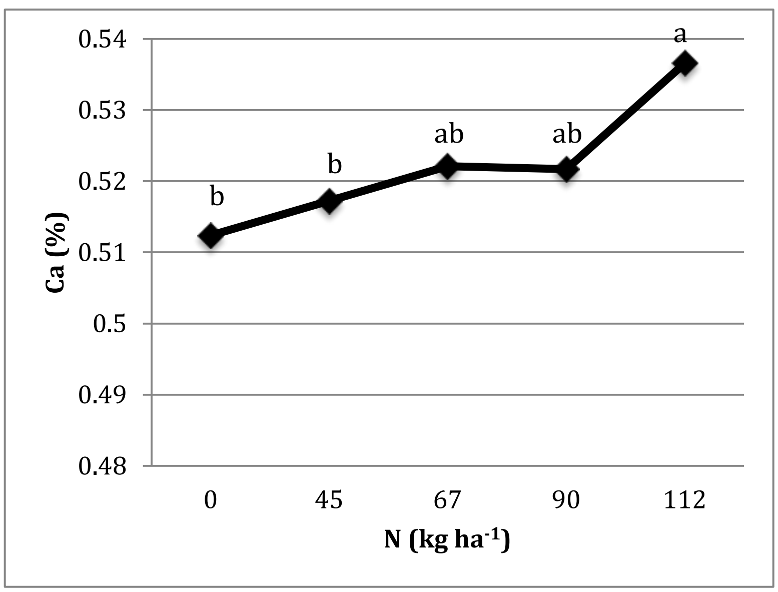

Fig. 34. Mean season average tissue Ca content based on pre-plant N at McGregor, TX in 2012. Treatments with the same letters are not statistically different according to Duncan's MRT.

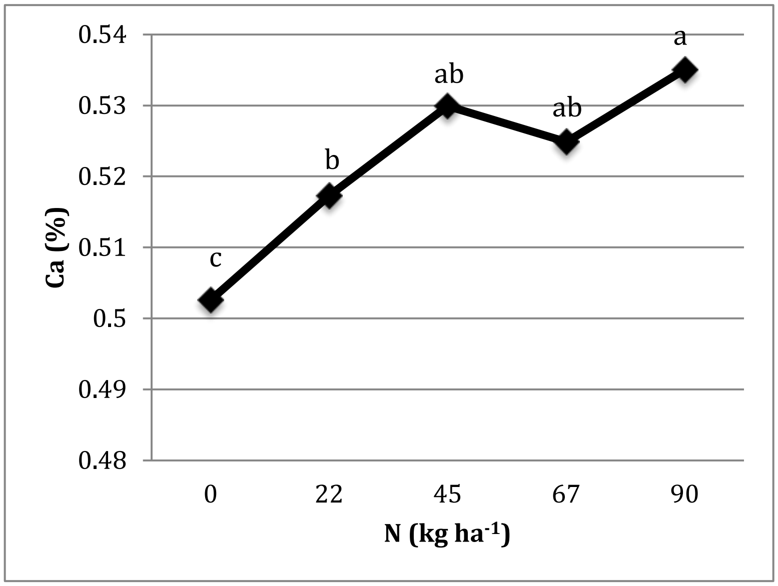

Fig. 35. Mean season average tissue Ca content based on top-dress N at McGregor, TX in 2012. Treatments with the same letters are not statistically different according to Duncan's MRT.

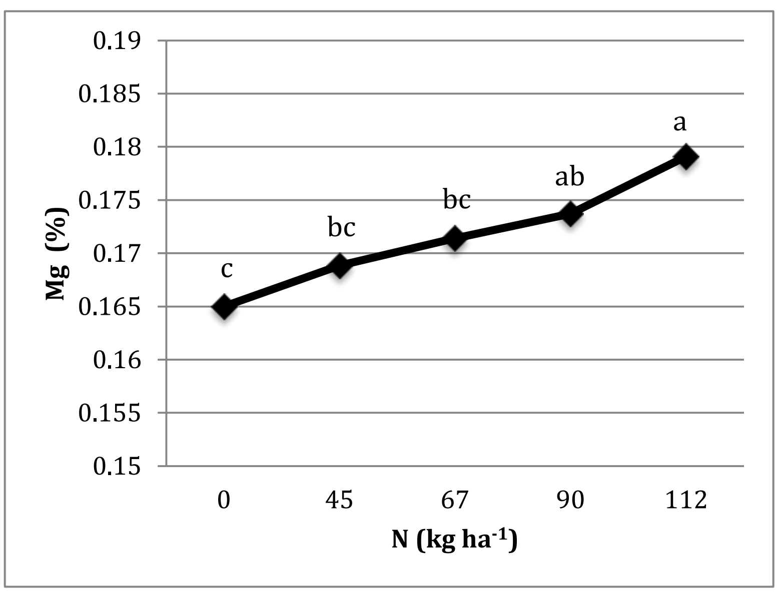

Fig. 36. Mean season average tissue Mg content based on pre-plant N at McGregor, TX in 2012. Treatments with the same letters are not statistically different according to Duncan's MRT.

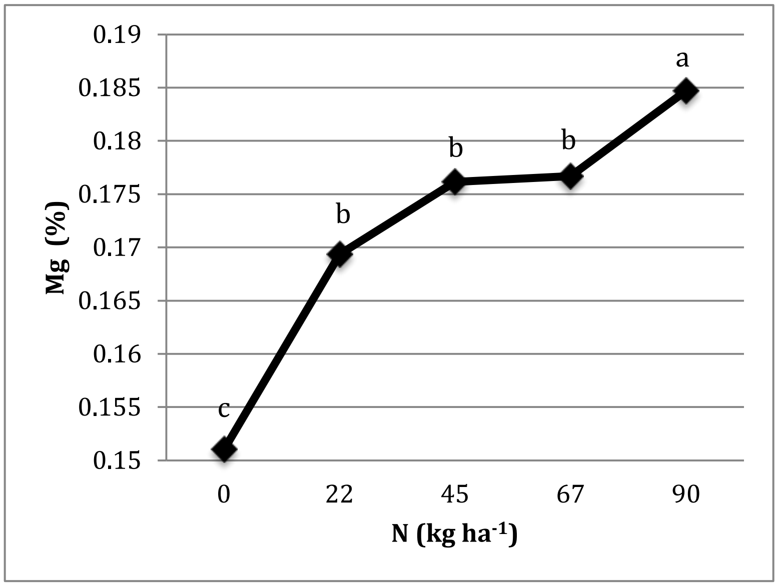

Fig. 37. Mean season average tissue Mg content based on top-dress N at McGregor, TX in 2012. Treatments with the same letters are not statistically different according to Duncan's MRT.

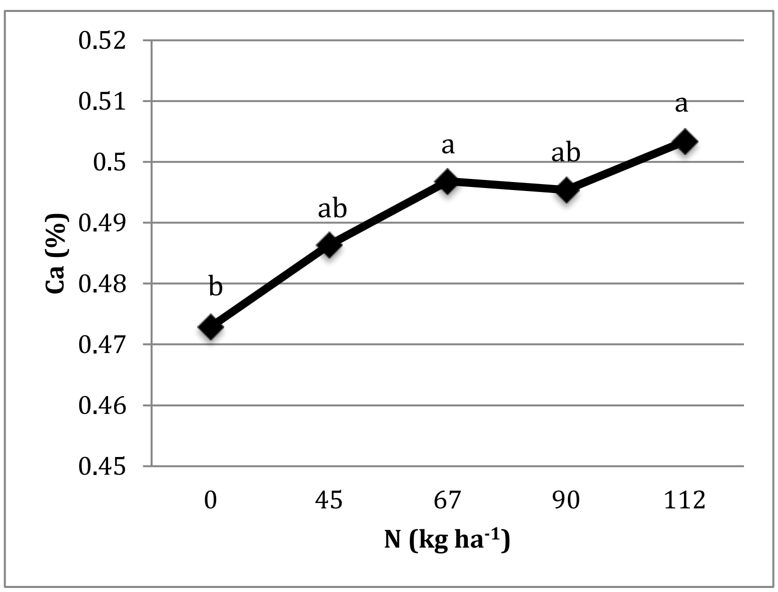

Fig. 38. Mean season average tissue Ca content based on pre-plant N at the Animal Science, Teaching, Research, and Extension Center (ASTREC), College Station, TX in 2012. Treatments with the same letters are not statistically different according to Duncan's MRT.

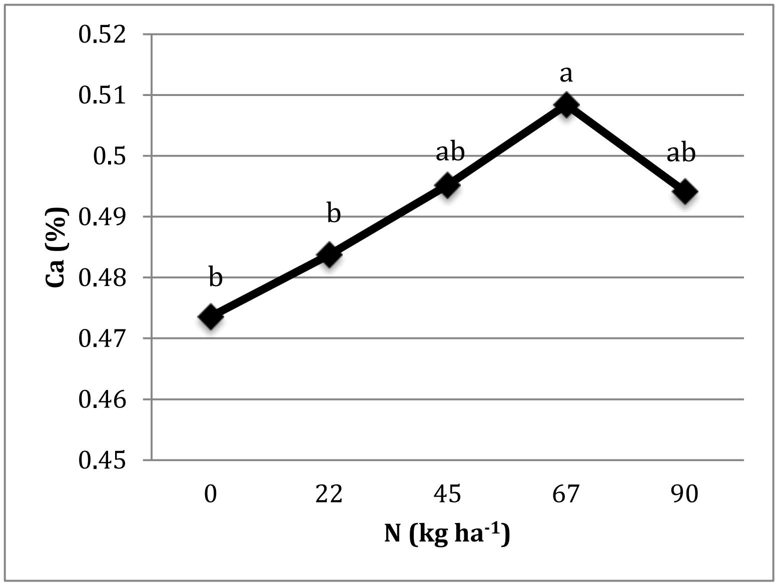

Fig. 39. Mean season average tissue Ca content based on top-dress N at the Animal Science, Teaching, Research, and Extension Center (ASTREC), College Station, TX in 2012. Treatments with the same letters are not statistically different according to Duncan's MRT.

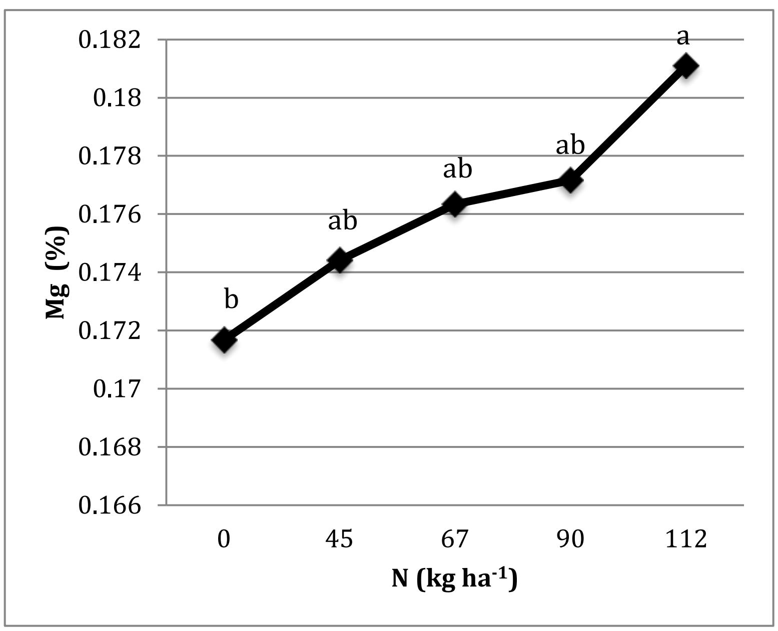

Fig. 40. Mean season average tissue Mg content based on pre-plant N at the Animal Science, Teaching, Research, and Extension Center (ASTREC), College Station, TX in 2012. Treatments with the same letters are not statistically different according to Duncan's MRT.

CHAPTER V

EVALUATION OF FORAGE QUANTIFICATION METHODOLOGIES

Introduction

Sampling methodology is a crucial factor in all scientific research. Significant uncertainty exists regarding the best method of quantifying biomass yield for forage research. While livestock grazing tests would be best for evaluating forage production based on animal performance, this method is labor intensive and requires an exorbitant amount of resources to conduct (Atkins, et al., 1969). Animal grazing also introduces a greater level of complexity to these studies in the form of performance dynamics associated with breed composition and production class in relation to the system studied. Several methods have been utilized in previous research including the use of hand tools to clip a sub sample from plots (Hubbard and Harper, 1949; Holt, 1962; Hansen and Schjoerring, 2003; MacKown and Carver, 2005) and the mechanized harvest of the entire plot (Worrall and Gilmore, 1985; Helsel and Thomas, 1987; Hossain, et al., 2003). These destructive methods are considered to be the best alternative methods for forage quantification, but problems related to plot size and high variability create issues (Wilm, et al., 1944). Wallace and Chapman (1956) conducted a study to determine optimum plot size to evaluate above ground biomass production in oat lines. They found that the greatest gain in precision through the reduction of the coefficient of variation was achieved with plot areas from 0.3716 m^2 to 0.7432 m^2. Atkins, et al. (1969) later confirmed these findings and noted that border protection is essential to the accuracy of forage trials.

In some cases, such as breeding programs, destructive sampling for the purpose of forage yield determination is not a feasible option, due to the nature of the research objectives or a lack of sufficient resources (Worrall and Gilmore, 1985; Ud-Din, et al., 1993; Paruelo, et al., 2000). To accommodate these instances, several non-destructive yield estimation methods have also been investigated including estimations based on plant height (Harmoney, et al., 1997; Freeman, et al., 2007), visual ratings (Atkins, et al., 1969; Ud-Din, et al., 1993), percent ground cover (Paruelo, et al., 2000), and Normalized Difference Vegetation Index (NDVI) readings (Serrano, et al., 2000; Hansen and Schjoerring, 2003; Moges, et al., 2005; Freeman, et al., 2007). Little consensus exists as to the best method of sampling for quantification purposes, as spatial variability is a major limiting factor in forage yield determination, and findings on the correlation of these methods with physical measurements of standing forage are inconsistent. It does appear that there is a consensus among authors that grain yield is not a good indicator of forage yield (Atkins, et al., 1969; Worrall and Gilmore, 1985; Ud-Din, et al., 1993).

In a range study where several biomass quantification techniques were investigated, Harmoney, et al. (1997) found that canopy height correlated well with destructive methods over all observations ($r^2 = 0.55$, $n = 212$). When partitioned by species, r^2 increased to 0.58 in warm season grass swards and 0.81 in cool-season grasses.

Visual estimation of above ground biomass has also been proven to be a useful evaluation tool. Atkins, et al. (1969) showed highly significant correlation coefficients when estimates from two individuals were combined for each of two cuttings, ($r = 0.55$ and 0.66, $P < 0.01$, respectively). However, the authors concluded that the estimators were ranking the cultivars too low as compared to the check cultivar, and within too low a range, but did not disclose the rating value range.

Paruelo, et al. (2000) investigated a photographic technique of biomass quantification in a range setting, where a photograph was taken of plots prior to harvest, then plant matter was separated into plant types. After analysis of the photographs, they found that green grass biomass showed a correlation of 0.87 ($n = 36$, $P < 0.001$) to percentage green pixels. Less of a relationship was seen when percentage green pixels was correlated to total green biomass ($r = 0.59$).

Serrano, et al. (2000) found no correlation between NDVI and biomass. However, Hansen and Schjoerring (2003) demonstrated that the use of NDVI calculated from red and near infrared reflectance is potentially useful. Moges, et al. (2005) also studied NDVI and its potential uses and found that red NDVI was highly correlated with biomass production in wheat at three harvest dates, Feekes 4, 6, and 10 (Miller, 1999), but that this correlation tended to decrease with increasing maturity. Freeman, et al. (2007) found that height, NDVI, and an index of the two predicted plant biomass and plant area biomass in corn. Several factors including growth stage, leaf area index, and mesophyll air space and have been implicated in the variability observed in the relationship between NDVI and biomass (Gausman, et al., 1971; Filella, et al., 1995;

Serrano, et al., 2000). Leaf area and canopy architecture, partially related to growth stage, were determined to have the greatest effect on canopy NIR reflectance (Serrano, et al., 2000). Several authors have indicated that NDVI was highly correlated with wheat N uptake at all growth stages (Filella, et al., 1995; Serrano, et al., 2000; Moges, et al., 2005).

The research objectives of this experiment were to evaluate minimally invasive, non-destructive, and destructive forage quantification methods to determine if any relationships exist between them. Significant relationships between destructive sampling and minimally invasive or non-destructive methods could prove the later to be a sufficient alternative to destructive forage quantification.

Materials and Methods

Experimental Locations

This research was initiated at three locations in central Texas. The first was located in the Brazos River Flood Plain (Brazos Bottom) near Snook, TX at the Texas A&M AgriLife Extension Farm (30° 30' N lat; 96° 25' W long; 66 m elevation above sea level.) This location is a Belk clay soil (fine, mixed, thermic Entic Hapluderts) exhibiting 0 to 1 % slopes. These soils are well drained with very slow permeability and high water holding capacity. The soil capability classification is 3S for non-irrigated, but was irrigated both years of the study. The second experimental location near College Station, TX at ASTREC (30° 33' N lat; 96° 24' W long; 83 m elevation above sea level.)

The soil type is a Roboco loamy fine sand (loamy, siliceous, active, thermic Aquic Arenic Paleustalfs) with a 1 to 3 % slope, moderate drainage, and rapid permeability in the upper layer with slow permeability in the subsoil. Large or repeated rainfall events can lead to a perched water table 0.5 to 1 m from the soil surface. The soil capability classification is 2E for non-irrigated. The third location was near McGregor, TX at the Texas A&M Agriculture Research and Extension Center (31° 22´ N lat; 97° 27´ W long; 240 m elevation above sea level). Soil type is a Slidell clay (fine, montmorillonitic, thermic Udic Haplusterts) with a 0- to 2 % slope, very slow permeability, and a high water holding capacity. The soil capability subclass was 2E for dryland and none was irrigated (NRCS, 2012).

This trial was conducted in conjunction with the N fertility trial discussed in the previous chapter. Data discussed in this chapter was taken from the same plots where the effect of N fertilizer rate on forage production in hard red winter wheat Fannin were evaluated. The trial was laid out in a split-plot randomized block design with each treatment replicated four times. PreN rate served as the main plot with PostN rate as the sub plot. Plots 1.5 m wide and 4.5 m long were used in this experiment.

Production Practices

In mid- to late-August, plot areas were disked or plowed to prepare the seedbed. Prior to planting, several soil samples were taken at each location to a depth of 60 cm, split into depth ranges (0-15 cm, 15-30 cm, 30-60 cm, and 60-90 cm), and composited based on depth range. Composite soil samples were obtained from each study location and submitted to the Texas A&M Soil, Water, and Forage Testing Lab for analysis. Routine soil analysis and stratified soil nitrate analysis (Texas A&M AgriLife Extension Service, 2012a) results can be found in Tables 25 and 26, respectively. Soils at each location were amended with triple super phosphate (0-46-0) to meet specified soil test recommendations based on the 0-15 cm samples from each location. P fertilizer was applied with a calibrated pendulum-type spreader and incorporated with harrows or with the wheat drill if applied directly before planting.

PreN treatments were surface applied as UAN (32-0-0) using a calibrated hand boom immediately prior to seeding in mid- to late-September. PreN application rates were determined by crediting soil test nitrate-N in the upper 15 cm of the soil to the PreN rates (0, 45, 67, 90, and 112 kg ha^{-1}) established in the trial protocol. The adjusted or as-applied PreN rates can be seen in Table 27. PostN treatments (0, 22, 45, 67, and 90 kg ha^{-1}) were applied in the same manner following each forage harvest. PostN treatments were not adjusted for soil N concentration.

A seven row Hege 500 small plot drill (Hege Equipment Inc., Colwich, KS) with 16.5 cm row spacing was used to plant seed and incorporate surface applied UAN. The planter was equipped with a cone type seed-metering device calibrated to plant a plot 1.5 m in width and 6 m in length. After emergence of seedlings in the experimental units, 1.5 m alleyways between replications were seeded, yielding 1.5 m wide, 4.5 m long plots for evaluation. This was done to ensure uniform stands over the experimental unit and to reduce any edge affect that would have resulted from blank alleys.

All plots were seeded with Fannin treated with the label rate of Gaucho XT® to prevent seedling disease and early-season insect damage. All plots were seeded at the rate of 100 kg ha^{-1}, the recommended rate for seeding small grains for forage production in central Texas.

Plot maintenance occurred on an as-needed basis and employed both mechanical and chemical pest control procedures. Herbicides used include 2, 4-D (0.5 L ha^{-1}), Finesse® Grass and Broadleaf herbicide (52 g ha^{-1}, chlorosulfuron and flucarbozone sodium), and Huskie® (1.1 L ha^{-1}, pyrasulfotol, bromoxynil octanoate, and bromoxynil heptanoate) were used to control any weed infestations present. To reduce yield losses due to insect pressure, applications of Dimethoate (0.25 L ha^{-1}) were made. Insect infestations including Greenbug (*Schizaphis graminum*), bird cherry-oat aphid (*Rhopalosiphum padi*), and army worm (*Pseudaletia unipuncta*) were observed and controlled.

Quantification Methodology

Forage yield and nutritive value were determined by three to four cuttings throughout the season, which occurred when sufficient above ground biomass accumulated (>1,345 kg ha^{-1}). Several non-destructive measurements were taken on each plot prior to harvest to evaluate each in its ability to predict dry biomass yield. An average plot height was obtained by measuring canopy height in two areas within the plot where forage height was representative of the whole plot. A numerical biomass rating, ranging from 1 to 10 with 1 denoting little biomass and 10 denoting the most biomass relative to all plots, was also assigned to each plot. Only odd number ratings were assigned to create a higher level of separation as well as to ease the evaluation process. A digital photograph was also taken 1.5 m directly above each plot to be used for determination of ground cover (GC). Pictures were taken from the North side of each plot close to noon to avoid shadowing. Images were loaded into Assess 2.0 image analysis software (APS Press, St. Paul, MN) and a macro utilizing the program's GC% feature was used to determine percent GC. A GreenSeeker® (N Tech Industries, Ukiah, CA) was also used to measure red and near infrared reflectance and convert that information into Normalized Difference Vegetative Index values (NDVI = (NIR – Red / NIR + Red)). The sensor was passed approximately 0.5 m above the canopy at walking speed, collecting 25 to 30 individual reflectance readings. These readings were averaged to give a mean NDVI value representing the entire plot.

Destructive sampling followed, with yield determination through hand clipping three 30.5 cm lengths of row from the interior of the plot to a height of 1.5 cm. A fresh weight was recorded for each sample, and then the three were combined. The remaining forage was then harvested to a stubble height of 1.5 – 2.5 cm with a Loftness flail type forage harvester equipped with a R-Tech Alfalfa-Omega weigh platform to collect forage weights (R-Tech Industries Ltd, MB, Canada). Hand clipping sample weights were then added to the plot weight measured by the full plot harvester to determine total forage wet weight.

Hand clipping samples were dried at 65° C for a minimum of 48 hours to ensure they were devoid of moisture. Once removed from the oven, samples were allowed to return to room temperature and weighed again to obtain a dry sample weight. The wet and dry sample weights were then used to determine percent weight loss, which was used to calculate the total dry matter biomass for each plot from both destructive methods.

Statistical Analysis

Statistical analysis was conducted with SAS version 9.3 (SAS Institute Inc. Cary, NC) (SAS Institute Inc., 2011) using the general linear model to perform analysis of variance and generate least squared means for each variable. Least square means from destructive and non-destructive quantification methods were correlated using Pearson's product-moment correlation to determine if relationships existed.

Results and Discussion

Over all, correlations showed potential for several alternative quantification methods. When samples from all locations and cuttings were pooled, canopy height (r = 0.45, $P < 0.01$) and hand clipping data (r = 0.75, $P < 0.01$) had the highest correlation with yield determined by harvesting the entire plot. Visual ratings and NDVI also had highly significant correlation (r = 0.32, $P < 0.01$ and r = 0.15, $P < 0.01$) with full plot harvest, but showed a weaker relationship with dry matter yield than canopy height and hand clippings. No relationship was seen between GC and full plot harvest. However, these correlation coefficients represent numerous observations made at several locations over a two-year period, making their application limited to long term observations. Due to the high level of variability observed within treatments, between cuttings due to growth stage, and between years, more precise measurements are often required.

The application of these minimally invasive and non-destructive measures over the period of a season or at a single point in time may be more useful to producers and forage research scientists alike, giving more precise measurements.

Across all locations, hand clippings showed the most consistent correlation with full plot harvest, showing highly significant, strong to moderate positive correlations at most cuttings. In 2011, high variability caused low correlation in the final cutting at three of the four locations. In 2012, a similar trend was observed, but variability associated with the first cutting caused insignificant correlations. Results also indicate that hand clippings may be a very useful option for season long forage yield determination. At all locations in 2011 and at ASTREC and the Brazos Bottom in 2012, correlation of hand clipping data from all cuttings by location showed highly significant strong to moderate positive correlation with full plot harvest. This suggests that hand clipping can be successfully used to predict dry matter yield regardless of growth stage (Tables 29 and 30).

Height data also correlated well with full plot forage yield on a per-harvest basis, most commonly showing a strong to moderate positive relationship. However, in some cases the first or last cutting at a location showed insignificant or weak to moderately negative relationships between canopy height and actual forage yield. As for use as a full-season forage prediction tool, height correlations were strong to moderate and showed positive correlation at 4 of the 7 study environments. At the remaining environments, height was negatively correlated with forage yield over the season. Negative relationships present when data from all clippings at a single location are combined indicates that the relationship between canopy height and dry matter yield may change over the season due to growth stage and canopy architecture. The degree to which wheat forms tillers due to environmental conditions may play a role in this relationship.

Visual ratings also showed highly significant, strong positive correlation to dry matter yield on a per-cutting basis at the Brazos Bottom and ASTREC in both years. At McGregor, little relationship was observed between visual ratings and dry matter yield. When data was combined by location, results showed significant positive relationships at environments except McGregor in 2012.

Table 29. Non-destructive and minimally invasive quantification methods correlated with full plot harvest data from forage trails at ASTREC, the Brazos Bottom, and McGregor in 2011.

Location†	Cutting ‡	Height	Visual Rating	NDVI	Ground Cover	Hand Clipping
				r		
ASTREC	1	0.73 **§	0.76 **	0.70 **	0.49 *	0.83 **
	2	-0.20	0.82 **	0.74 **	0.10	0.24
	All	0.85 **	0.39 **	-0.31 *	-0.42 **	0.63 **
Brazos Bottom A	1	0.87 **	0.93 **	0.49 *	0.68 **	0.75 **
	2	0.41 *	0.66 **	0.49 *	-0.05	0.57 **
	3	0.51 **	0.55 **	0.23	0.53 **	0.58 **
	4	0.69 **	0.35	0.44 *	0.21	0.59 **
	All	-0.18	0.80 **	0.84 **	0.83 **	0.79 **
Brazos Bottom B	1	0.57 **	0.68 **	0.54 **	-	0.69 **
	2	0.77 **	0.75 **	0.82 **	-0.10	0.74 **
	3	0.63 **	0.58 **	0.36	-0.12	0.65 **
	4	0.03	0.48 *	0.46 *	-0.06	0.35
	All	-0.37 **	0.17	0.37 **	0.33 **	0.91 **
McGregor	1	0.24	0.41 *	0.03	0.11	0.52 **
	2	0.49 *	0.10	-	-	0.35
	All	0.79 **	0.35 *	0.03	0.11	0.58 **

† ASTREC, Animal Science, Teaching, Research, and Extension complex. The same trial was conducted in two areas at the Brazos Bottom.

‡ All, denotes that the following correlation coefficients represent data points from all cuttings at that location.

§ Asterisks, * and **, denote significant difference from r = 0 at $P < 0.05$ and $P < 0.01$, respectively.

Table 30. Non-destructive and minimally invasive quantification methods correlated with full plot harvest data from forage trails at ASTREC, the Brazos Bottom, and McGregor in 2012.

Location†	Cutting ‡	Height	Visual Rating	NDVI	Ground Cover	Hand Clipping
				r		
ASTREC	1	0.56 **§	0.71 **	0.51 **	0.56 **	0.37
	2	0.37	0.58 **	0.71 **	-0.12	0.65 **
	All	0.38 **	0.66 **	0.14	-0.28	0.60 **
Brazos Bottom	1	-0.08	0.33	0.00	0.14	0.11
	2	0.74 **	0.60 **	0.56 **	0.82 **	0.62 **
	3	0.75 **	0.76 **	0.19	0.07	0.80 **
	All	0.85 **	0.21	0.17	-0.57 **	0.77 **
McGregor	1	0.43 *	0.44 *	-	0.06	0.62 **
	2	-0.47 *	-0.34	-0.05	-0.05	-0.05
	3	-0.03	0.12	-0.09	0.05	-0.20
	All	-0.26 *	-0.10	-0.22	-0.18	0.17

† ASTREC, Animal Science, Teaching, Research, and Extension complex.

‡ All, denotes that the following correlation coefficients represent data points from all cuttings at that location.

§ Asterisks, * and **, denote significant difference from r = 0 at $P < 0.05$ and $P < 0.01$, respectively.

NDVI also performed well in 2011, showing significant positive correlation with dry matter yield at most cuttings at all locations except McGregor, where no significant correlation was observed. Both studies at the Brazos Bottom in 2011 showed little correlation between NDVI and dry matter for the third cutting. Both of these experiments were harvested on the same day, when wheat was between Feeks 5 and 6. Complete ground cover and strongly erect growth may have been the factor that created a lack of differentiation in NDVI between plots with different biomass levels present, creating insignificant correlation with dry matter, which agrees with the findings of Serrano, et al. (2000). In 2012, NDVI from both cuttings at ASTREC and the second cutting at the Brazos Bottom showed highly significant, strong positive correlation with dry matter yield. The remainder of cuttings at the Brazos Bottom and all at ASTREC yielded insignificant, weak or negative relationships. When data from all cuttings were combined by location and year, correlations were highly variable. NDVI may prove to be better suited to dry matter predictions at one point in time, and in forages where complete ground cover is not achieved over variable biomass yield.

Ground cover measurements proved to have little relationship with dry matter yield. It may, however, be an acceptable predictor of early season forage, as high correlation was observed in the first or second cutting at several locations. It was observed that in some cases, green light reflected from leaves projected onto the soil surface, causing a lack of differentiation between soil and green foliage.

CHAPTER VI

CONCLUSIONS

Evaluation of Winter Wheat and Oat Under Dual-Purpose Management

Environmental conditions are a primary factor in the performance of dual-purpose systems. Within environments, cultivar selection can affect the productivity of the system, as evident by significant environment-by-cultivar interactions on each variable measured. With respect to environmental conditions, cultivars that consistently yielded well in 2012 are most likely those that are more advantageous, possessing traits that allow them to take benefit of favorable conditions. Cultivars that performed well when unfavorable conditions prevailed in 2011 and consistently under favorable conditions are more utilitarian and drought resistant. As for selecting specific cultivars that performed well, few consistencies were seen. High variability in forage yield coupled with a non-existent to negative correlation with grain yield also hindered the ability of this study to identify one or a group of cultivars that perform well under this type of management. However, we did find that oats yielded less forage than did either class of wheat. This agrees with the findings of Worrall and Gilmore (1985) that determined oat to be an inferior small grain forage crop for in the Rolling Plains. The results of a study conducted by Edmisten, et al. (1998a) showed the same trend in wheat and oats cut during the vegetative stages, although it was not proven statistically. They did, however, show that wheat and barley produced significantly higher dry matter yield in plots where clipping was initiated in each growth stage after vegetative growth. This would suggest that oat may not be a suitable dual-purpose crop, as maximizing fall and winter forage production is a primary goal.

Nutritive values were inconsistent across locations, with the exception of Mg levels. Oat consistently had significantly higher Mg concentrations than either class of wheat. Edmisten, et al. (1998b) found that nutritive value of wheat and barley was generally higher than oat and rye. Our data did not identify a superior species.

Grain yield was also somewhat variable, but some patterns were evident. HRW and SRW performed well as compared to oat under dry conditions. SRW also out yielded HRW and oat when growing conditions were not limited by drought. This suggests that SRW may be a superior plant for grain production in Central Texas. Unfortunately, grain yield and forage yield did not correlate well, meaning those exhibiting high forage yield did not also yield well at grain harvest. An example of one cultivar that did seem to out-perform others in both forage and grain production was the HRW cultivar Doans (AP02T4342).

Further research is needed to identify cultivars that consistently perform well in forage and grain production. Vastly contrasting years yielded highly variable results across years and locations, but we were able to determine which class of wheat or oat consistently performed well under each type of environmental conditions. Contrasting environmental conditions also enabled us to identify cultivars that yielded consistently regardless of conditions and those that were more opportunistic, increasing yield under favorable conditions. These findings will provide small grains producers who implement dual-purpose management systems with management type specific performance information to aid in cultivar selection.

Nitrogen Rate and Timing Effect on Forage Production in Winter Wheat

At the Brazos Bottom location in 2011, severe drought conditions limited forage growth potential and nutrient uptake. High levels of residual soil N also reduced the effectiveness of the study at this location; however, some valid conclusions can be drawn from results obtained this location. Addition of pre-plant fertilizer can reduce stand establishment when persistent drought conditions are prevalent. In these situations, forage production is also affected due to reduced stand establishment. Although wheat can compensate for low plant population, forage production lost early in the season has a great effect on season total forage production. The production losses sustained due to PreN fertilizer averaged 220 kg ha^{-1}, which while seemingly insignificant would account for $40 of gain per ha. Persistent drought conditions also made moisture the most limiting factor in forage growth potential, reducing the need for N.

At the Brazos Bottom location in the 2012, when soil moisture was less of a limiting factor added N led to differences in forage yield. There was little response to PreN treatments, but this may be attributed to high levels of residual soil N. This suggests that 67 kg ha^{-1} residual soil N at planting is sufficient to support maximum forage production in both wheat classes in that environment. In relation to top-dress N application, dry matter yield means showed that the 45 kg ha^{-1} PostN treatment produced the most additional forage per unit N applied as compared to other treatments.

Soil residual N levels were much lower at the ASTEC location and yield means at ASTREC also showed a benefit in pre-plant N application. At this location, the 90 kg ha^{-1} PreN treatment yielded the most forage. Soil type, predominately clayey at the Brazos Bottom and sandy at ASTREC, is probably responsible for the discrepancy between results at these locations. Sandy soils are much more susceptible to leaching when heavy precipitation events occur. PostN treatments at the ASTREC location produced the same results as those seen at the Brazos Bottom in 2012.

Forage yield results from McGregor were very different from that seen at other locations, but we did see that early season forage production is an important part of total forage yield. A negative relationship between forage yield and applied N was also seen in the second cutting, which may be attributed to tissue damage resulting from top-dress urea ammonium nitrate application. However, no tissue damage data was collected; therefore, we could not confirm this hypothesis.

Added N also positively affected forage nutritive values in most cases. Forage CP content was positively related to N applied in most environments. When precipitation was not limiting and growth rates were high, PreN treatments seemed to have less effect on CP content than when yield was low. Multiple top-dress applications and high levels of residual soil N probably masked the effect of pre-plant N in these cases. Pre-plant N may have been more of an influence on CP content at ASTREC due to low levels of residual soil N creating a greater need for starter N.

Overall, nutritive value data seemed to suggest that as forage growth increased, nutritive value was diluted. Increased forage production in the latter part of the 2012 season at ASTREC and the Brazos Bottom show fewer significant differences in nutrient content, with the exception of Ca and Mg at ASTREC. Unexplained inconsistency of the results is probably due to the intricacy of the N cycle, the dynamic relationship between defoliation and root mass, and experimental error.

Evaluation of Forage Quantification Methodologies

Overall, hand clipped sub samples proved to have the highest correlation with full plot dry matter yield, with a majority of r values being 0.5 or higher ($r = -0.2 – 0.83$). This was expected due to the similarities between methods, although it did not fully explain the variability in dry matter yield determined through full plot harvest. Canopy height and visual rating were also closely related to dry matter yield in many cases, but some insignificant or negative correlations were also seen. These findings are probably a result of canopy architecture and weight distribution associated with changes in growth stage. Correlation of height and dry matter yield was weak in the first cutting of the season and last cutting of the season in several instances. Lack of correlation in early season forage production may be more closely related to development of tillers rather than leaf growth and elongation. Late in the season, the shift from vegetative growth to reproductive growth in the form of head development and grain filling most likely contributed more to dry matter weight than did height in the form of straw. Canopy height and visual ratings were highly correlated, thus the relationship of both was most likely similar.

Ground cover measurements had the weakest or most variable relationship with dry matter yield, and correlations were weak. NDVI also showed high correlation with forage yield, but again some data sets produced negative correlations. Canopy height and density were most likely the cause of weak correlation with dry matter. Both NDVI and ground cover measurements may have limited ability to predict density of forage stands after canopy closure is achieved. More research is needed to determine more specific reasons for the trends observed. Growth stage, canopy architecture, and degree of tillering may explain some of the variation seen between non-destructive methods and full plot dry matter yield, especially for the NDVI and ground cover measurements. Both of these methods may be ineffective in distinguishing different levels of biomass after complete ground cover is achieved.

REFERENCES

Atkins, I.M., O.G. Merkle and P.E. Pawlisch. 1969. Visual estimates and clipping plot size for evaluating the forage potential of small grain varieties. Agron. J. 61: 88-91. doi:10.2134/agronj1969.00021962006100010030x.

Beck, P.A., D.S. Hubbell, K.B. Watkins, S.A. Gunter and L.B. Daniels. 2005. Performance of stocker cattle grazing cool-season annual grass mixtures in Northern Arkansas. The Professional Animal Scientist. 21: 465-473.

Briggle, L.W. and B.C. Curtis. 1987. Wheat worldwide. In: E. G. Heyne, editor Wheat and wheat improvement. ASA, CSSA, SSSA, Madison, Wis. , USA. p. 765.

Carter, O. 1967. The effect of chemical fertilizers on seedling establishment. Australian J. of Experi. Agric. 7: 174-180. doi:http://dx.doi.org/10.1071/EA9670174.

Carver, B.F., I. Khalil, E.G. Krenzer and C.T. MacKown. 2001. Breeding winter wheat for a dual-purpose management system. Euphytica. 119: 231-234. doi:10.1023/a:1017543800311.

Carver, B.F., E.G. Krenzer and W.E. Whitmore. 1991. Seasonal forage production and regrowth of hard and soft red winter wheat. Agron. J. 83: 533-537. doi:10.2134/agronj1991.00021962008300030003x.

Cherney, J.H. and G.C. Marten. 1982. Small grain crop forage potential: I. Biological and chemical determinants of quality, and yield. Crop Sci. 22: 227-231. doi:10.2135/cropsci1982.0011183X002200020007x.

Clarke, J.M., C.A. Campbell, H.W. Cutforth, R.M. DePauw and G.E. Winkleman. 1990. Nitrogen and phosphorous uptake, translocation, and utilization efficiency of wheat in relation to environmental and cultivar yield and protein levels. Canadian J. of Plant Sci. 70: 965-977. doi:10.4141/cjps90-119.

Collins, F.C. and J.P. Jones. 1978. Registration of bob oat (reg. No. 290). Crop Sci. 18: 913-913. doi:10.2135/cropsci1978.0011183X001800050069x.

Croy, L.I. 1983a. Effects of clipping and grazing termination date on grain production. National Wheat Pasture Symposium, Stillwater, OK.

Croy, L.I. 1983b. Variety and species effects on forage quantity, forage quality and animal performance. National Wheat Pasture Symposium, Stillwater, OK. Oklahoma Agricultural Experiment Station.

Daigger, L.A., D.H. Sander and G.A. Peterson. 1976. Nitrogen content of winter wheat during growth and maturation. Agron. J. 68: 815-818. doi:10.2134/agronj1976.00021962006800050033x.

Donnelly, K.J. and W.E. McMurphy. 1983. Cultural practices for maximizing forage production in wheat. National Wheat Pasture Symposium, Stillwater, OK. Oklahoma Agricultural Experiment Station.

Edmisten, K.L., J.T. Green, J.P. Mueller and J.C. Burns. 1998a. Winter annual small grain forage potential. I. Dry matter yield in relation to morphological characteristics of four small grain species at six growth stages. Commun. Soil Sci. Plant Anal. 29: 867-879. doi:10.1080/00103629809369992.

Edmisten, K.L., J.T. Green, J.P. Mueller and J.C. Burns. 1998b. Winter annual small grain forage potential. Ii. Quantification of nutritive characteristics of four small grain species at six growth stages. Commun. Soil Sci. Plant Anal. 29: 881.

Epplin, F.M., I. Hossain and E.G. Krenzer Jr. 2000. Winter wheat fall–winter forage yield and grain yield response to planting date in a dual-purpose system. Agricultural Systems. 63: 161-173. doi:10.1016/s0308-521x(00)00004-4.

Epplin, F.M., E.G. Krenzer, Jr. and G. Horn. 2001. Net returns from dual-purpose wheat and grain-only wheat. The Journal of the ASFMRA. 8-8.

ERS. 1997. Oat farm characteristics, income, and production costs. http://webarchives.cdlib.org/sw1s17tt5t/http://ers.usda.gov/publications/fbei/fbei-oat.pdf (accessed June 28, 2012).

ERS. 2012a. Average u.S. Farm prices of selected fertilizers, 1960-2012,. http://www.ers.usda.gov/data/fertilizeruse/ (accessed June 18, 2012).

ERS. 2012b. Wheat: Background. http://www.ers.usda.gov/briefing/wheat/background.htm (accessed June 10, 2012).

ERS. 2012c. Wheat: Overview. http://www.ers.usda.gov/topics/crops/wheat.aspx (accessed June 28, 2012).

FAO. 2012. Faostat database. http://faostat.fao.org/site/567/DesktopDefault.aspx?PageID=567 - ancor (accessed May 12, 2012).

Filella, I., L. Serrano, J. Serra and J. Peñuelas. 1995. Evaluating wheat nitrogen status with canopy reflectance indices and discriminant analysis. Crop Sci. 35: 1400-1405. doi:10.2135/cropsci1995.0011183X003500050023x.

Freeman, K.W., K. Girma, D.B. Arnall, R.W. Mullen, K.L. Martin, R.K. Teal, et al. 2007. By-plant prediction of corn forage biomass and nitrogen uptake at various growth stages using remote sensing and plant height. Agron. J. 99: 530-536. doi:10.2134/agronj2006.0135.

Gausman, H.W., W.A. Allen, D.E. Escobar, R.R. Rodriquez and R. Cardenas. 1971. Age effects of cotton leaves on light reflectance, transmittance, and absorptance and on water content and thickness. Agron. J. 63: 465-469. doi:10.2134/agronj1971.00021962006300030035x.

Gradberry, S. 2001. Beef cattle nutrition series part 3: Nutrient requirement tables. University of Arkansas Division of Agriculture.

Grunes, D.L., D.P. Hutcheson, F.P. Horn, B.A. Stewart and D.J. Unersander. 1983. Mineral composition of wheat forage as related to metabolic disorders of ruminants. National Wheat Pasture Symposium, Stillwater, OK. Oklahoma Agricultural Experiment Station

Hanks, R.J. and F.C. Thorp. 1956. Seedling emergence of wheat as related to soil moisture content, bulk density, oxygen diffusion rate, and crust strength. Soil Sci. Soc. Am. J. 20: 307-310. doi:10.2136/sssaj1956.03615995002000030003x.

Hansen, P.M. and J.K. Schjoerring. 2003. Reflectance measurement of canopy biomass and nitrogen status in wheat crops using normalized difference vegetation indices and partial least squares regression. Remote Sens. Environ. 86: 542-553. doi:10.1016/s0034-4257(03)00131-7.

Harmoney, K.R., K.J. Moore, J.R. George, E.C. Brummer and J.R. Russell. 1997. Determination of pasture biomass using four indirect methods. Agron. J. 89: 665-672. doi:10.2134/agronj1997.00021962008900040020x.

Helsel, Z.R. and J.W. Thomas. 1987. Small grains for forage. J. Dairy Sci. 70: 2330-2338.

Holliday, R. 1956. Fodder production from winter sown cereals and its effect on grain yield. Field Crops Abstracts. 9: 129-135, 207-213.

Holt, E.C. 1962. Growth behavior and management of small grains for forage. Agron. J. 54: 272-276.

Horn, F.P. 1983. Chemical composition of wheat pasture. National Wheat Pasture Symposium, Stillwater, OK. Oklahoma Agricultural Experiment Station.

Horn, G.W., P.A. Beck, J.G. Andrae and S.I. Paisley. 2005. Designing supplements for stocker cattle grazing wheat pasture. J. Anim. Sci. 83: E69-E78.

Horn, G.W., W.E. McMurphy and R.L. Mitchell. 1981. Forage production and digestibility of small grains forage. Oklahoma Agr. Exp. Sta.: MP-108.

Hossain, I., F.M. Epplin and E.G. Krenzer. 2003. Planting date influence on dual-purpose winter wheat forage yield, grain yield, and test weight. Agron. J. 95: 1179-1188. doi:10.2134/agronj2003.1179.

Hubbard, V.C. and H.J. Harper. 1949. Effect of clipping small grains on composition and yield of forage and grain. Agron. J. 41: 85-92.

Khalil, I.H., B.F. Carver, E.G. Krenzer, C.T. MacKown and G.W. Horn. 2002. Genetic trends in winter wheat yield and test weight under dual-purpose and grain-only management systems. Crop Sci. 42: 710-715. doi:10.2135/cropsci2002.7100.

Krenzer, E.G., J.D. Thompson and B.F. Carver. 1992. Partitioning of genotype × environment interactions of winter wheat forage yield. Crop Sci. 32: 1143-1147. doi:10.2135/cropsci1992.0011183X003200050016x.

Krenzer, E.G.J., A.R. Tarrant, D.J. Bernardo and G.W. Horn. 1996. An economic evaluation of wheat cultivars based on grain and forage production. J. Prod. Agric. 9: 66-73.

Lyon, D.J., D.D. Baltensperger and M. Siles. 2001. Wheat grain and forage yields are affected by planting and harvest dates in the central great plains. Crop Sci. 41: 488-492. doi:10.2135/cropsci2001.412488x.

MacKown, C.T. and B.F. Carver. 2005. Fall forage biomass and nitrogen composition of winter wheat populations selected from grain-only and dual-purpose environments. Crop Sci. 45: 322-328. doi:10.2135/cropsci2005.0322.

Marshall, D. and R. Sutton. 2004. Registration of sturdy 2k. Crop Sci. 44: 355-356.

Miller, T.D. 1999. Growth stages of wheat: Identification and understanding improve crop management. http://varietytesting.tamu.edu/wheat/docs/mime-5.pdf (accessed May 15).

Mitchell, L.G., C.A. Grant and G.J. Racz. 2000. Effect of nitrogen application on concentration of cadmium and nutrient ions in soil solution and in durum wheat. Canadian J. of Soil Sci. 80: 107-115. doi:10.4141/s98-085.

Moges, S.M., W.R. Raun, R.W. Mullen, K.W. Freeman, G.V. Johnson and J.B. Solie. 2005. Evaluation of green, red, and near infrared bands for predicting winter wheat biomass, nitrogen uptake, and final grain yield. J. Plant Nutr. 27: 1431-1441. doi:10.1081/pln-200025858.

NASS. 2012a. Quick stats. http://quickstats.nass.usda.gov/ (accessed June 12, 2012).

NASS. 2012b. Cattle. http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1017 (accessed May 12, 2012).

National Research Council. 1996. Nutrient requirements of beef cattle. 7th ed.National Academy of Sciences.

National Weather Service. 2012a. College station extremes, normals and annual summaries. http://www.srh.noaa.gov/hgx/?n=climate_cll_normals_summary (accessed September 19).

National Weather Service. 2012b. Mcgregor, TX climatology,. http://www.srh.weather.gov/fwd/?n=mcgregorclimatology (accessed October 15).

Nelson, L.R. 1983. National Wheat Pasture Symposium, Stillwater, OK. Oklahoma Agricultural Experiment Station.

NRCS. 2012. Web soil survey. NRCS.

Paruelo, J.M., W.K. Lauenroth and P.A. Roset. 2000. Estimating aboveground plant biomass using a photographic technique. J. Range Manage. 53: 190-193. doi:10.2307/4003281.

Pinchak, W.E., W.D. Worrall, S.P. Caldwell, L.J. Hunt, N.J. Worrall and M. Conoly. 1996. Interrelationships of forage and steer growth dynamics on wheat pasture. J. Range Manage. 49: 126-130.

Redmon, L.A. 2011. Personal communication with state forage specialist. Texas A&M AgriLife Extension Service. TAMU.

Redmon, L.A., G.W. Horn, E.G. Krenzer and D.J. Bernardo. 1995a. A review of livestock grazing and wheat-grain yield - boom or bust. Agron. J. 87: 137-147.

Redmon, L.A., F.T. McCollum, III, G.W. Horn, M.D. Cravey, S.A. Gunter, P.A. Beck, et al. 1995b. Forage intake by beef steers grazing winter wheat with varied herbage allowances. J. Range Manage. 48: 198-201.

Roberts, C.A., J. Stuth and P.C. Finn. 2003. Nirs applications in forages and feedstuffs. In: C. A. Roberts, J. Workman and J. Reeves, editors, Near-infrared spectroscopy in agriculture. ASA, CSSA, and SSSA, Madison, WI. p. 321.

Rommann, L.M., R.A. Johnston and W.E. McMurphy. 1982. Forage production from small grain, 1982.Cooperative Extension Service, Division of Agriculture, Oklahoma State University.

SAS Institute Inc. 2011. Sas/stat users guide, version 9.3. SAS Institute Cary, NC, USA.

Serrano, L., I. Filella and J. Peñuelas. 2000. Remote sensing of biomass and yield of winter wheat under different nitrogen supplies. Crop Sci. 40: 723-731. doi:10.2135/cropsci2000.403723x.

Stewart, B.A., D.L. Grunes, A.C. Mathers and F.P. Horn. 1981. Chemical composition of winter wheat forage grown where grass tetany and bloat occur. Agron. J. 73: 337-347. doi:10.2134/agronj1981.00021962007300020022x.

Texas A&M AgriLife Extension Service. 2012a. Methods and method references. http://soiltesting.tamu.edu/webpages/swftlmethods1209.html (accessed Sept. 28).

Texas A&M AgriLife Extension Service. 2012b. Nitrogen soil fertility recommendations for forage crops. http://soiltesting.tamu.edu/files/soilrecs/forageN.pdf (accessed Sept. 28).

Texas A&M Agrilife Extension Service. 2012c. Variety testing information: Small grains. http://varietytesting.tamu.edu/wheat/ (accessed Jan. 20).

Ud-Din, N., B.F. Carver and E.G. Krenzer. 1993. Visual selection for forage yield in winter wheat. Crop Sci. 33: 41-45. doi:10.2135/cropsci1993.0011183X003300010005x.

USDA. 2004. Chapter 7: Oats. Grain inspection handbook. USDA. p. 1-3.

Wallace, A.T. and W.H. Chapman. 1956. Studies in plot technique for oat clipping experiments1. Agron. J. 48: 32-35. doi:10.2134/agronj1956.00021962004800010009x.

Wilm, H.G., D.F. Costello and G.E. Klipple. 1944. Estimating forage yield by the double-sampling method. Agron. J. 36: 194-203. doi:10.2134/agronj1944.00021962003600030003x.

Winter, S.R. and E.K. Thompson. 1987. Grazing duration effects on wheat growth and grain yield. Agron. J. 79: 110-114. doi:10.2134/agronj1987.00021962007900010023x.

Winter, S.R. and E.K. Thompson. 1990. Grazing winter wheat: I. Response of semidwarf cultivars to grain and grazed production systems. Agron. J. 82: 33-37. doi:10.2134/agronj1990.00021962008200010007x.

Winter, S.R., E.K. Thompson and J.T. Musick. 1990. Grazing winter wheat: II. Height effects on response to production system. Agron. J. 82: 37-41. doi:10.2134/agronj1990.00021962008200010008x.

Worrall, W.D. and E.C. Gilmore. 1985. Forage production of small grains for the rolling plains. Texas Agricultural Experiment Station Miscellaneous Publication. 1-5.

APPENDIX A

Table 31. Mean squares of type 3 test of random effects for combined analysis of dual-purpose forage yield components collected at ASTREC†, the Brazos Bottom, and McGregor, TX in 2011 and 2012.

Source			Forage					
	df	Stands	df	Yield	df	Protein	df	TDN‡
Cultivar	39	15.73 ***	39	1947070 **	37	6.83 ***	37	7.53 **
Environment	4	480.97 ***	4	861610230 ***	4	642.86 ***	4	412.21 ***
Rep(Environment)	15	7.21 ***	15	3051363 ***	9	28.80 ***	9	37.88 ***
Environment*Cultivar	152	5.72 ***	152	1726098 ***	122	5.30 ***	122	8.16 ***
Error	573	915.98	561	985928	308	2.89	308	3.42
			Grain					
			df	Yield	df	Test Weight	df	Protein
Cultivar			39	2381493 ***	39	1662.66 ***	29	0.00033 ***
Environment			4	72158367 ***	4	221.66 ***	4	0.00976 ***
Rep(Environment)			15	476667 ***	15	6.28 ***	15	0.00046 ***
Environment*Cultivar			152	815330 ***	150	26.75 ***	116	0.00011 **
Error			560	82886	531	1.34	432	0.00007

† ASTREC, Animal Science, Teaching, Research, and Extension Complex.
‡ TDN, total digestable nutrients.
* Significant at the 0.05 level.
** Significant at the 0.01 level.
*** Significant at the 0.001 level.

Table 32. Mean squares of type 3 test of random effects for combined analysis of dual-purpose forage yield components collected at early and late forage harvests at the Brazos Bottom, in College Station, TX in 2011 and 2012.

Source	Early Season Forage §								
	df	Yield		df	Protein		df	TDN‡	
Cultivar	39	1710504		37	7.4		37	10.4	
Environment	1	541011618	***	1	42.9		1	2379.9	***
Rep(Environment)	6	1758825	*	6	7.6	*	6	11.8	
Environment*Cultivar	37	1351012	***	29	9.1	***	29	9.8	*
Error	226	667169		197	3.5		197	6.0	
	Late Season Forage ¶								
	df	Yield		df	Protein		df	TDN	
Cultivar	39	848954		37	11.2	*	37	5.5	
Environment	1	50668512	***	1	1580.5	**	1	1050.5	**
Rep(Environment)	6	1021297	**	6	66.2	***	6	63.2	***
Environment*Cultivar	37	596299	**	29	6.1		29	4.3	
Error	228	325789		198	6.3		198	5.0	

† ASTREC, Animal Science, Teaching, Research, and Extension Complex.
‡ TDN, total digestable nutrients.
§ Dry matter yield prior to December 15.
¶ Dry matter yield after December 15.
* Significant at the 0.05 level.
** Significant at the 0.01 level.
*** Significant at the 0.001 level.

Table 33. Mean squares of type 3 test of random effects for combined analysis of stand establishment and total forage yield of the fertility experiments conducted at ASTREC†, the Brazos Bottom, and McGregor, TX in 2011 and 2012.

Source ‡	df	Stands		df	Total Yield	
Environment	2	4912.83	***	3	519409624	***
Rep(Environment)	9	142.29	**	9	3292377	
PreN*Environment	8	43.53		12	1780850	**
PostN*Environment				12	1849478	***
PreN	4	60.98		4	1049665	
PostN				4	2858092	
PreN*PostN				16	504968	
PreN*Rep				12	1266917	
PreN*PostN*Rep				60	733406	***
Error	276	39.27		250	630937	

† ASTREC, Animal Science, Teaching, Research, and Extension Complex.
‡ PreN, pre-plant N treatment. PostN, top-dress N treatment.
* Significant at the 0.05 level.
** Significant at the 0.01 level.
*** Significant at the 0.001 level.

Table 34. Mean squares of type 3 test of random effects for combined analysis of average forage nutritive values of the fertility experiments conducted at ASTREC†, the Brazos Bottom, and McGregor, TX in 2011 and 2012.

Source ‡	df	Protein		df	TDN §		df	P		df	K		df	Ca		df	Mg	
Environment	3	1231.92	***	3	1637.01	***	3	15018011	***	3	1635933004	***	3	26207707	***	3	4807060	***
Rep(Environment)	9	11.72	***	9	17.24	***	9	111966	**	9	11866366	***	9	1332419	***	9	85718	***
PreN*Environment	12	3.11	*	12	1.81	*	12	28585		12	2840707		12	113153		12	14924	
PostN*Environment	12	8.12	***	12	4.26	***	12	130465	***	12	5873510	*	12	210851	***	12	59356	***
PreN	4	20.89	***	4	4.95	***	4	327126	**	4	4576904		4	270109		4	47263	*
PostN	4	67.86	**	4	16.39	*	4	1140427	**	4	31624336	*	4	241967		4	198718	*
PreN*PostN	16	1.54		16	0.56		16	40302		16	1225030		16	31618		16	15145	
PreN*Rep	12	1.25		12	0.33		12	55196		12	3091223		12	120415		12	13232	
PreN*PostN*Rep	60	1.96		60	1.10		60	34067		60	2417230		60	69218		60	10287	
Error	257	1.64		257	0.86		257	37434		257	2669685		257	68513		257	12373	

† ASTREC, Animal Science, Teaching, Research, and Extension Complex.
‡ PreN, pre-plant N treatment. PostN, top-dress N treatment.
§ TDN, total digestable nutrients.
* Significant at the 0.05 level.
** Significant at the 0.01 level.
*** Significant at the 0.001 level.

Table 35. NIR calibration equation r-squared values for forage nutritive value parameters measured.

	Protein	ADF†	NDF	ADL	IVDMD
r^2	0.969	0.903	0.885	0.911	0.943

	P	K	Ca	Mg
r^2	0.757	0.893	0.721	0.664

† ADF, acid detergent fiber; NDF, neutral detergent fiber, ADL, acid detergent lignin; IVDMD, in vitro dry matter digestability.